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IN QUEST OF CLEAN AIR FOR BERLIN, NEW HAMPSHIRE

Paul A. Kenline

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1962

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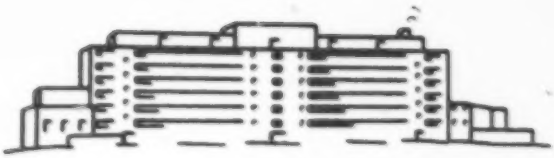

The Robert A. Taft
Sanitary Engineering Center
TECHNICAL REPORT
A62-9

IN QUEST OF CLEAN AIR

FOR BERLIN, NEW HAMPSHIRE

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U. S. DEPARTMENT OF HEALTH,
EDUCATION, AND WELFARE
Public Health Service

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IN QUEST OF CLEAN AIR

FOR BERLIN, NEW HAMPSHIRE

Paul A. Kenline
Field Studies Branch
Division of Air Pollution

Report of a Cooperative Survey

by the

U. S. Public Health Service

Details of illustrations in this document may be better studied on microfiche.

State of New Hampshire
Department of Health
Bureau of Occupational Health

City of Berlin, New Hampshire
Health Department

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Air Pollution

Robert A. Taft Sanitary Engineering Center
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1962

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SURVEY STAFF

Project Supervisor
Forrest H. Bumford
Director, Bureau of Occupational Health
New Hampshire State Department of Health

Project Director
Paul A. Kenline
Division of Air Pollution
Public Health Service
U. S. Department of Health, Education, and Welfare

Public Health Service Personnel
Willis Bye, Engineer
Richard Dickerson, Chemist
Earl Markee, Meteorologist
Peter Ricca, Engineer
Charles Walters, Meteorological Technician

New Hampshire State Department of Health Personnel
Richard Dumm, Engineer
Frederick Langevin, Chemist
George Morrill, Engineer
Stewart Stokes, Engineer

Berlin City Health Department Personnel
Edward J. Montminy, City Health Officer

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IN QUEST OF CLEAN AIR FOR BERLIN, NEW HAMPSHIRE

SUMMARY AND RECOMMENDATIONS

The U. S. Public Health Service, New Hampshire State Department of Health, and Berlin City Health Department conducted an appraisal of the nature, sources, extent, and effects of air pollution in Berlin, New Hampshire.

Berlin, with a population of 15,000, is a manufacturing area. Manufacturing accounts for over half of all employment, with one plant, The Brown Company, accounting for 80 percent of this total. The population has shown a gradual decrease since 1930.

The city proper occupies 4 square miles, and is situated in a well-developed, Y-shaped valley system. The valley walls rise 500 to 800 feet within a mile of the city's center. The valley topography greatly influences the meteorological regime and handicaps the ability of the atmosphere to adequately disperse pollutants. Frequent inversions, confinement of lateral dispersion, and weak winds allow periods of pollutant accumulation.

Pollutants of concern in Berlin include particulates, sulfur dioxide, hydrogen sulfide, and malodorous organic sulfur gases. A comparison of emissions (in pounds per year) from various sources is given in Table 1.

Table 1. Emissions from Various Sources in Berlin

Source	Particulate, lb/yr	Sulfur dioxide, lb/yr
Domestic fuel consumption	194,000	1,811,000
Automobiles	65,000	140,000
Industrial fuel consumption	6,500,000	4,043,000
Industrial processes	2,320,000	22,830,000
Total	11,054,000	28,824,000

The major source of air pollutants is the pulping and ancillary operations, including steam generation. Other sources do not play an important role in the overall situation. The specific major sources of pollutants include kraft digesters, kraft chemical recovery system, sulfite chemical recovery system, and boiler plant.

Measurements of air quality are summarized in Table 2.

Table 2. Air Quality Measurements for Berlin

Pollutant	Average	Maximum
Suspended particulate, $\mu g/m^3$	183	309
Hydrogen sulfide, ppb	-	23
Sulfation, $\mu g\ SO_3/100\ cm^2$ per day	426	1069
Dustfall per 30 days, tons/mi^2	35	68
Soiling, Coha/1000 ft	0.9	1.9
Sulfur dioxide, ppb	16	33

Levels of suspended particulate matter and dustfall are relatively high, compared to levels measured in other areas. Levels of sulfur dioxide, hydrogen sulfide, and malodors, although not generally or consistently high, do reach levels where undesirable effects are produced. Pollution is heaviest in areas near the pulp mill and tends to carry down the valley.

Air pollution problems exist in Berlin and have reached levels that justify constructive efforts to ameliorate the situation. Undesirable effects in Berlin have been shown to include soiling, excessive dustfall, paint damage, vegetation damage, and unpleasant odors. These effects cost money, interfere with the enjoyment of property, contribute to the deterioration of the community, and constitute a variety of annoyances. The effect of pollu-

tion on health was not investigated as a part of this specific study, but implications of other research conducted in Berlin and elsewhere should be considered (note pp 3 and 33).

Complete control of pollutant emission cannot be attained, and the solution to some of the pollution problems is very difficult; however, certain measures can be undertaken that will result in a considerable reduction in pollution emission and improve air quality. Certain measures and evaluations to this effect are presented.

What steps should be taken to improve air quality in Berlin? Emissions from other than industrial operations are not of sufficient magnitude to warrant consideration of control measures. Based on findings of this study, the following initial steps are warranted. Since all of these relate to the Brown Company, their cooperation must be solicited. It is suggested that the Berlin City Council request the Brown Company to undertake the first seven items and report their findings to the council. The last two items require diligence on the part of the company with regard to operation and good housekeeping.

1. Evaluate the sulfur dioxide emission of the MGO stack over a period of at least a month, covering all operating conditions. Samples should be taken directly from the stack through the existing sample tap (the aspirator line now being used is not adequate).

2. Inspect the venturi-separator packed-tower system of the MGO plant for condition of equipment; investigate the operation of this system for adequacy. If the sulfur dioxide emission is as large as this study indicates, and this investigation shows that equipment and operation are satisfactory, then modification of the existing system is called for.

3. Evaluate the efficiency of the lime kiln spray washer by sampling for particulates up- and down-stream. If this efficiency is less than 85 percent, modification of the spray washer or of its operation is warranted.

4. Evaluate the use of secondary scrubbers on the recovery furnace stack. A cost-efficiency study may disclose that all or a substantial portion of the cost of such equipment may be offset by recovered saltcake and sulfur compounds.

5. Install a mesh-demister on the smelt (dissolving) tank stack.

6. Consider the possibility of black liquor oxidation. This is partly an economic consideration, but more prominently a process consideration, since it decidedly alters the process of pulp production.

7. Evaluate the cost of installing equipment for collecting and destroying blow and relief gases from the kraft digesters and for collecting particulates from the Heine boilers. The cost of such equipment, which does not result in any economic advantage of recovered product, must be balanced against anticipated emission reduction with resulting community good will and better public relations.

8. Proper operation of the recovery furnace and Heine boilers must be insured, to materially reduce the magnitude of emissions. Proper maintenance and operation of existing control equipment (MGO venturi scrubbers, lime kiln spray, smelt tank spray) must be maintained.

9. Production capacity should not be greatly exceeded; over-loading the equipment greatly increases pollutant emission.

INTRODUCTION

DEFINING THE SUBJECT

Air pollution is the presence in the ambient atmosphere of substances, put there by the activities of man, in concentrations sufficient to interfere directly or indirectly with his comfort, safety, or health, or with the full use and enjoyment of his property.

For an air pollution problem to exist, three factors must be present: a source of pollutants, a susceptible population or other receptor, and a means of transport between the two (a mechanism controlled by topography and weather).

Community air pollution arises from many of the activities of man. It comes from the combustion of fuel for home heating, for power generation in industry, and for transportation. It comes from the disposal of wastes and refuse. It comes from many industrial processes. And it comes from many other activities by man, individually or collectively.

Fortunately nature has provided a huge reservoir of unpolluted air and the mechanism necessary to insure dispersion of man's contaminants by air currents. These natural processes sometimes proceed at a slow rate, however, and whenever man's activities discharge noxious or troublesome substances at a rate faster than those processes operating to disperse or destroy them, a build up in pollution concentration occurs and persists until natural forces can again cope with the situation.

Air pollution adversely affects man in many ways; at times and under certain circumstances the effects have been serious. Acute episodes of air pollution throughout the world are known to have caused illness and death. Just as important, and perhaps more difficult to deal with than the acute episodes, is the possibility that air pollution may be responsible for chronic health impairment in our population. In addition, air pollution can act upon exposed mucous membranes, causing eye, throat, and nasal irritation. Such irritation, combined with the general nuisance effects of air pollution, produces an as yet unmeasured but perhaps significant amount of psychological harm to people.

Air pollution affects man in many other important ways. It imposes extra costs on the population, in terms of metal corrosion, damaged buildings, soiled laundry and fabrics, and deterioration of paint. It damages vegetation and livestock and reduces visibility. It interferes with man's enjoyment of his surroundings, contributes greatly to the physical deterioration of communities, constitues a variety of annoyances, and is frequently offensive to the senses.

Determination of the existence of air pollution problems is not always based solely on known or suspected adverse effects on health, comfort, safety, or economics; public opinion is often the criterion. It is the responsibility of official agencies to point out unsatisfactory conditions, actual or potential, when such are not obvious to the public, so that suitable community action will develop.

STUDY PROCEDURE

The purpose of this survey is to make an appraisal of the nature, sources, extent, and effects of air pollution in Berlin. To accomplish this purpose the following activities were undertaken: measurement of air pollution levels in the community atmosphere, measurement of weather factors and analysis of effects of weather and topography on dispersion of pollution, evaluation of emissions to the atmosphere based on emission factors and measurements, and evaluation of effects of pollution.

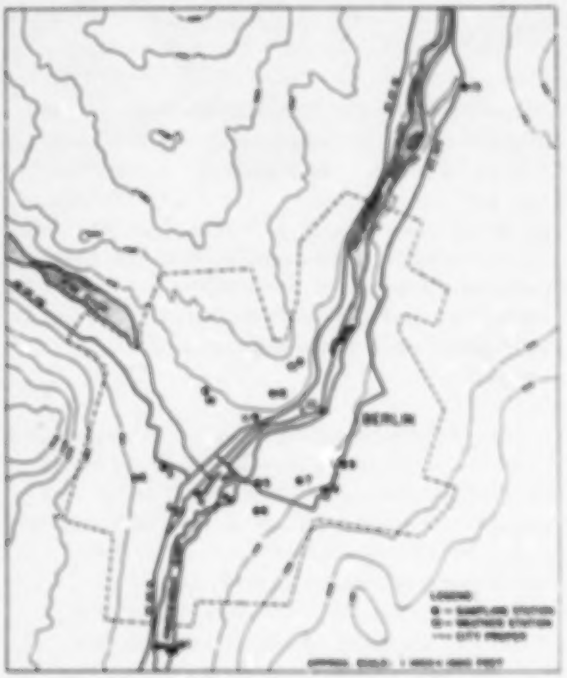


Figure 1. Air sampling and meteorological stations.

Nine stations were established to measure dustfall and sulfur dioxide (sulfation). These stations were located at the Powerhouse, St. Joseph School, Penstock, Community Field, Angel Guardian School, Derrah Street, Berlin Junior High School, Notre Dame High School, and out Route 16-A. These stations were operated from July 28 to October 4, 1960. Three of these stations, Angel Guardian, Berlin Junior High, and Community Field, were operated through May, 1961. At the Community Field station (Unity and Mason Streets) additional measurements were made for hydrogen sulfide, suspended particulates, soiling, and sulfur dioxide. This station was operated from August 3 to October 4, 1960.

An additional station was set up at St. Louis Hospital to sample for suspended particulates, hydrogen sulfide, and soiling. This station was operated from September 9 to September 28, 1960.

Table 1. LEGEND FOR FIGURE 1.

Station number	Station name	Measurements
1	Powerhouse	dustfall, sulfation
2	St. Joseph School	dustfall, sulfation
3	Armory	fabric
4	Penstock	dustfall, sulfation
5	Community Field	dustfall, sulfation, hi-vol, hydrogen sulfide, soiling, sulfur dioxide
6	Berlin Foundry	fabric
7	King School	fabric
8	Angel Guardian School	dustfall, sulfation, fabric
9	Derrah Street	dustfall, sulfation
10	Berlin Jr. High School	dustfall, sulfation, fabric
11	St. Louis Hospital	hi-vol, hydrogen sulfide, soiling
12	Notre Dame High School	dustfall, sulfation, fabric
13	Route 16A	dustfall, sulfation
A	Glen and Pleasant	wind direction, wind speed, temperature, humidity
B	Susan Street Playground	temperature, humidity
C	Main and First	wind direction, wind speed

Continuous measurement of wind speed, wind direction, and wind trace type were made at two 55-foot towers, one erected at Glen and Pleasant Streets and the other at Main and 1st Streets. Continuous measurements of temperature and humidity were made at two stations, one at Glen and Pleasant Streets and the other at the playground at the end of Susan Street.

The air sampling and meteorological stations are shown in Figure 1. The legend for Figure 1 is given in Table 3.

Sampling of emissions of pollutants were performed on stacks of the recovery furnace, MGO plant, smelt tank, blow system, lime kiln, and boiler plant. These tests were performed during the period August 23 through October 4, 1960.

Methods and equipment used for the community network sampling, meteorological measurements, and emission sampling are given in Appendix A.

Examination for possible air pollution effects on vegetation was made in the Berlin area on October 22 and 23, 1960, by a representative of the U. S. Department of Agriculture. Various fabrics (rayon, nylon, cotton, and wool) were exposed at six stations (the Armory, Berlin Foundry, King School, Angel

Guardian School, Berlin Junior High School, and Notre Dame High School) to evaluate damage to materials. Ceramic tiles impregnated with lead acetate were exposed at all sampling sites to evaluate the areal distribution of hydrogen sulfide and its blackening effect. Paint samples from blackened houses were examined for sulfide. Odor levels were evaluated on a spot basis by use of a scentometer.

GENERAL CONSIDERATIONS

Berlin, county seat of Coos County, is situated in the Androscoggin River valley at the northern edge of the White Mountains' Presidential Range. The river valley is well defined. Berlin is a manufacturing area with little or no agriculture or mining. The area has some scenic-recreational aspects and is a source of timber. Berlin was incorporated as a city in 1897 and has an area of 61.7 square miles, of which approximately 4 square miles contains the city proper. Two state routes, three bus lines, two railroads, and an airline service the city. The mean annual temperature is 43.5°F and the annual rainfall averages 32.5 inches.

POPULATION

The general public is responsible for the emission of certain pollutants. These derive from their daily activities, including the combustion of fuels for heat, power, and transportation, and the burning of rubbish. The contribution of an individual is small, but taken collectively the sum of these emissions may well amount to a large quantity. In sparsely settled areas, these emissions are dispersed into a large volume of air and are readily assimilated into the atmosphere. As population density increases, more pollutants are released into the given volume of air and it becomes increasingly difficult for the atmosphere to disperse them. Population figures are also an index of future pollution levels, since population increase is generally accompanied by an increase in pollution emission, both from the activities of the general public itself and from accompanying increased industrial-commercial activity.

Table [illegible] POPULATION DENSITIES 1950[17]

Area	Population	Land area, mi.²	Density, persons/mi.²
City of Berlin	16,615	61.7	270
City proper	25,000	6.0	3,750
Coos County	39,932	1,822	20
County less City	23,317	1,760	11

Table 5. POPULATION TRENDS[17]

Year	Berlin	Berlin area[a]	Coos County
1900	9,486	-	-
1930	20,018	23,500	36,959
1940	19,184	22,463	39,174
1950	16,615	25,317	39,932

[a]Berlin, Gorham, and Milan.

The population of Berlin was 16,615 in 1950, a decrease of 2569 from the 1940 census. Recent estimates of population indicate a further decrease but of lesser magnitude. Population densities (Table 4) are low; even within the city proper the population concentration is typical of an urban fringe area. The population of Berlin and nearby areas has not grown in recent years, and actually has decreased (Table 5). Since population growth does not appear likely, air pollution levels are not expected to increase as a general trend.

GENERAL CHARACTER OF INDUSTRY AND EMPLOYMENT

Table 6 shows the total employment in Berlin and compares its distribution with that of Coos County and the United States. Manufacturing accounts for over half of Berlin's employment - this ratio is almost twice the national average. Agriculture and mining are relatively unimportant in the area.

Table 6. EMPLOYMENT BY GENERAL CATEGORY[38]

Industry	City of Berlin Number	City of Berlin %	Coos County, %	United States, %
Agriculture and Forestry	46	0.8	9.1	11.0
Mining	1	0.0	0.0	1.4
Construction	183	3.2	5.2	5.1
Manufacturing	3129	54.4	47.7	28.5
Transportation, Communication, and Public Utilities	292	5.0	6.0	5.1
Trade	926	16.1	15.2	19.1
Finance, Insurance, and Real Estate	78	1.4	1.5	3.9
Services and Miscellaneous	739	12.8	15.3	11.9
Government	363	6.3		12.1

Table 7. MANUFACTURING PLANTS IN BERLIN [5]

Company	Employees	Weekly payroll
Berlin Foundry & Machine Co.	19	$ 1,900
Brown Company	3,000	288,460
E. M. Cross Machine Co.	10	1,000
Granite State Rubber Co.	548	32,430
Ware Knitters, Inc. of N.H.	110	4,500
White Mt. Lumber Co.	65	5,000

There are six manufacturing establishments in Berlin (Table 7). One plant, The Brown Company, accounts for 80 percent of the total employment. Principal products of these establishments are: sulfate and sulfite pulps, Bermico pipe, insoles, chemicals, knitted outerware, lumber, canvas footwear, and machining.

LAND USE

Land usage may be generally described by noting that the major industrial complex lies along the river in the northern section of the city and that residential areas lie elsewhere within areas dictated by topography. Proximity of several residential areas to the industrial area may be expected to aggravate pollution problems.

GENERAL APPRAISAL OF AIR POLLUTION SOURCES

Air pollution arises from a bewildering complexity of sources. In evaluating pollution sources in Berlin, we shall consider four general classes of potential emission: (1) combustion of fuel for heating, (2) disposal of waste, (3) combustion of fuel for transportation, and (4) industrial processes, including industrial fuel consumption.

FUEL USAGE

The major fuel used for domestic heating is oil (Table 8). Coal constitutes the balance of heating fuel. Gross comparison of these data with fuel used for residential heating in 1950 (Table 9) indicates a decline in use of wood and coal, with a corresponding increase in use of fuel oil.

Emission factors from Appendix B were used to approximate potential emissions from fuel combustion (Table 10).

These values, although not sufficiently reliable to indicate actual emissions, can be used to assess the general nature and character of an area's air pollution potential. Even under rather severe weather conditions, emissions of this magnitude would not constitute a potentially serious community-wide problem. Emissions from domestic heating are not

Table 8. FUEL CONSUMPTION IN BERLIN - 1959

Fuel	Amount	Approximate Billions of Btu's	Percent Btu's
Coal	6,424 tons	145	11.4
Oil	8,000,000 gallons	1,110	86.9
Wood	180 cords	4	0.3
Bottled gas	8,600 cylinders (100 lb)	18	1.4

Table 9. FUEL USED FOR RESIDENTIAL HEATING - 1950[36]

Fuel	Number of Dwelling Units	Percent of Dwelling Units
Coal	955	21.8
Wood	265	6.0
Bottled gas	110	2.5
Liquid	2,945	67.1
Other	115	2.6

constant over the year, but occur during colder weather. It may be anticipated that emissions from this source occur in proportion to the heating degree-days (Table 11). Thus the 5-month period, November through March, accounts for 75 percent of these emissions.

Table 10. POTENTIAL EMISSIONS FROM DOMESTIC FUEL CONSUMPTION IN POUNDS PER YEAR

Pollutant	Coal	Oil	Wood	Gas	Total
Sulfur oxides	118,202	1,692,840	56	0	1,811,098
Nitrogen oxides	2,570	761,778	416	5,934	770,698
Hydrocarbons	192,720	282,140	6,940	1,290	483,090
Aldehydes	--	101,570	625	860	103,055
Organic acids	128,480	846,420	139	1,032	976,071
Particulate	154,176	14,107	902	0	169,185

Table 11. HEATING DEGREE-DAYS[a] FOR BERLIN

Month	Degree-Days	Percent of Degree-Days
Jan	1519	17.9
Feb	1341	15.8
Mar	1184	14.0
Apr	744	8.8
May	391	4.6
June	99	1.2
July	0	0.0
Aug	25	0.3
Sept	267	3.1
Oct	589	6.9
Nov	933	11.0
Dec	1392	16.4
Annual	8484	100.0

[a]These values of degree-days are based on calculations derived from annual and monthly mean temperatures.[42]

WASTE DISPOSAL OPERATIONS

The means of disposal of garbage, refuse, and other wastes is an important factor in any community's air pollution potential. The burning of refuse on open dumps or in "backyard incinerators" can be a major source of air pollution (Appendix B). Properly constructed and operated municipal incinerators are a great improvement over such operations, but they may still emit gaseous products of combustion and limited amounts of particulate matter and odors, which may constitute a localized nuisance. The most desirable method of waste disposal for the elimination of pollution is the sanitary landfill. In a landfill refuse is not burned but is thoroughly compacted and covered with soil or other suitable fill at least once a week.

Berlin disposes of its wastes by use of a well-operated landfill. Some burning is allowed at the disposal site. Miscellaneous wood and paper refuse are burned at The Brown Company's dump off Success Pond Road north of the City. Waste disposal does not constitute a significant source of pollution in Berlin.

TRANSPORTATION

The role of motor vehicle exhausts in air pollution is of increasing concern in large communities throughout the country. These vehicles emit significant quantities of hydrocarbons and nitrogen oxides, and relatively smaller amounts of aerosols, sulfur oxides, and other organic materials. Other pollutants result from the use of additives to gasoline and from the use of motor oil and its additives.

Motor vehicle registrations numbered 7000 in 1959. Estimates of potential emissions from these vehicles are given in Table 12. These values are small.

Table 12. POTENTIAL EMISSION FROM AUTOMOBILES (HIGHLY VARIABLE)

Pollutant	Pollutant, lb/yr
Sulfur oxides	41,958
Nitrogen oxides	526,806
Aldehydes	18,648
Other organics	23,310
Hydrocarbons	1,547,784
Particulates	51,282

Daily traffic counts on the routes into and out of Berlin are reported as:

Route 110, 700 vehicles
Route 16N, 1200 vehicles
Route 16S, 4800 vehicles

This amount of traffic would not make a major contribution to the over-all community air pollution problem, although localized nuisance conditions from odors and smoke may be anticipated along congested downtown routes.

The conditions necessary for occurrence of photochemical smog are sufficient gasoline consumption, a low-level inversion, weak winds, and intense sunshine. In comparing gasoline consumption to photochemical smog damage to plants in and near metropolitan areas, Went[46] reported that when gasoline consumption reaches 12 tons per square mile per day smog damage to plants may occur during adverse meteorological conditions. Gasoline consumption in Berlin is much lower than this figure.

Other transportation means as potential sources of pollutants are insignificant in this area.

INDUSTRIAL SOURCES

Of the six manufacturing establishments in Berlin (Table 7) only The Brown Company possesses a capacity large enough to significantly contribute to the local air pollution problem. Emissions from industrial sources, from both processes and fuel usage, are given in the section "Source Survey."

SOURCE SURVEY

Samples of effluents from various stacks were taken during the period August 23 through October 4, 1960. Sampling was performed on stacks considered to be major emitters of pollutants. Stacks sampled, number of runs made, and general methods used are summarized in Table 13.

Table 13. EMISSION SAMPLING

Stack	Number of Runs	Method[a]
Recovery furnace	9	A
	3	B
MGO stack	6	C
Smelt tank	2	A
Blow system	2	A
Lime kiln	4	D
Heine boilers	5	E

[a]Method A[25] measures sulfur dioxide, hydrogen sulfide, total organic sulfur gas, and particulates. Method B[1] measures all gasses by a gas chromatographic technique. Method C[25, 47] measures sulfur dioxide and particulates. Method D[48, 47, 25] measures sulfur dioxide, hydrogen sulfide, and particulates. Method E[48] measures particulates.

KRAFT (SULFATE) MILL

Two types of air pollution result from the kraft process: pollution by solid particles and pollution by gases and objectionable odor. Solid particles originate mainly from the recovery furnace (composed approximately[49] of 45 percent sodium carbonate, 40 percent sodium sulfate, 5 percent sodium sulfite, 2.5 percent sodium hydroxide, 1 percent sodium sulfide, and 6.5 percent carbon and other material), from the lime kiln (composed essentially of lime dust and sodium salts), and from the power plant (composed of flyash, soot, and unburned carbon).

The unpleasant cabbage-like odor, which is characteristic of the kraft process, is caused mainly by a group of organic sulfur compounds, of which the most important are methyl mercaptan and its oxidation products, dimethyl disulfide and dimethyl sulfide. Hydrogen sulfide, which has an odor of rotten eggs, is also produced in the kraft process. The major sources of odorous and nonodorous gases are the recovery furnace (sulfur dioxide, hydrogen sulfide, and methyl mercaptan and its oxidation products), the digester relief and blow gases (hydrogen sulfide, methyl mercaptan and its oxidation products, methanol, and other gases), the evaporators (hydrogen sulfide, and methyl mercaptan and its oxidation products), the lime kiln (sulfur dioxide and hydrogen sulfide), and the power plant (sulfur dioxide). In addition there are a number of other odor emission points, which individually may be relatively unimportant but which in the aggregate are sufficient

Table 14. EMISSIONS FROM RECOVERY FURNACE STACK

Run	Stack temp., °F	Gas velocity, fps	Gas emission, cfm	Hydrogen Sulfide		Sulfur Dioxide		Particulate	
				Concentration, ppm	Emission, lb/hr	Concentration, ppm	Emission, lb/hr	Concentration, gr/ft^3	Emission, lb/hr
1	270	34.3	103,000	470	250	31	31	0.100	88
2	298	42.4	127,500	-	-	19	24	-	-
3	281	39.6	119,000	-	-	65	75	-	-
4	304	37.6	113,000	565	331	63	70	0.093	91
5	271	38.4	115,000	597	356	58	65	0.109	108
6	277	36.7	110,000	619	354	42	45	0.106	100
7	277	36.7	110,000	690	394	78	84	0.106	100
8	304	40.3	121,000	537	310	0	0	-	-
Average	285	38.2	115,000	580	332	45	50	0.103	97
Maximum	-	-	-	690	-	78	-	0.109	-
Minimum	-	-	-	470	-	0	-	0.093	-
Standard deviation	-	-	-	68	45	25	27	0.006	7

to produce a significant odor problem even if the major sources are completely controlled.

Recovery Furnace

Pollutant emissions measured in the recovery furnace stack are summarized in Table 14. The concentration of hydrogen sulfide in the stack gas was 580 parts per million (by volume) and the emission of this gas was 330 pounds per hour. Sulfur dioxide concentration was 45 ppm and its emission was 50 pounds per hour. The concentration of particulates was 0.10 grain per cubic foot (at stack conditions) and particulate emission was 97 pounds per hour. At standard temperature and pressure (32°F, 1 atm) and adjusted to 12 percent carbon dioxide, the average particulate loading adjusts to 0.37 grain per standard cubic foot. This is higher than the value established by Los Angeles for combustion contaminants (0.3 gr/std ft^3 at 12 % carbon dioxide), but well below the usual legal limitation set by most cities.

The emission of sulfur dioxide (50 lb/hr) is minor. Its concentration, 118 milligrams per cubic meter, is at the lower end of values reported in the literature (15-950 mg/m^3) for recovery furnace emissions.

The emission of hydrogen sulfide (330 lb/hr) is probably sufficient to cause some paint damage; a dilution of 750 fold is necessary to reduce this below odor threshold. The concentration of hydrogen sulfide, 760 milligrams per cubic meter, is towards the middle of values reported in the literature (35-1200 mg/m^3).

Results of sampling for other sulfur gases (as methyl mercaptan and its oxidation products) are not available at this time. On the basis of values reported in the literature, however, a concentration of roughly 130 milligrams per cubic meter may be anticipated for methyl mercaptan. This would require a dilution of approximately 100 to 1 to reach odor threshold. When results of sampling for these reduced sulfur compounds are available, they will be published as an addendum and this estimated value will be corrected.

Blow System

The blow system discharges to the atmosphere through two stacks: one ties into the accumulator system and is designated as the accumulator stack and the other ties into the digesters and is designated as the relief stack. During a blow both stacks discharge. A blow occurs a little less than once an hour and generally lasts from 10 to 15 minutes. Thus this

Table 15. EMISSIONS FROM BLOW SYSTEM

	Relief	Accumulator
Gas temperature, °F	170	170
Gas velocity, fps	20	20
Gas emission, cfm	1950	6050
Hydrogen sulfide concentration, ppm	304	-
Hydrogen sulfide emission, lb/hr	3	-
Sulfur dioxide concentration, ppm	0.6	1.4
Sulfur dioxide emission, lb/hr	0.012	0.08

system is not a continuous source of pollutants. Measurements of emissions were made with the sampler developed at the University of Florida. Use of this sampler was only partially successful. Total organic sulfur and particulates were not obtained because of partial malfunction of equipment and extreme wetness of the gas. The high concentrations of methyl mercaptan and associated gases interfered to some extent with the hydrogen sulfide analysis. Emission data for the blow system are summarized in Table 15.

Information in the literature on blow system emissions are meager; however, a rough rule is that the concentration of methyl mercaptan is 10 times that of hydrogen sulfide (by weight) and that of dimethyl sulfide is 2 times that of methyl mercaptan, during a blow. Hence, we may speculate that emission from the relief stack may be about:

	Concentration, ppm	Emission, lb/hr
Hydrogen sulfide	300	3
Methyl mercaptan	2000	30
Dimethyl sulfide	2800	60

Concentrations of these gases from the accumulator stack should be about the same, and emissions about double those stated. The twofold difference in sulfur dioxide concentrations indicated in Table 15 is not inconsistent with this idea, since the production of this gas is highly variable. On this basis a dilution of the blow gas of more than 7000 to 1 is necessary to reduce the gas to the odor threshold. It should be clearly understood that this is quite speculative, and not supported by direct evidence.

Table 16. EMISSIONS FROM THE SMELT (DISSOLVING) TANK

	Run 1	Run 2
Gas temperature, °F	175	173
Gas velocity, fps	52	50
Gas emission, cfm	20,600	20,100
Hydrogen sulfide concentration, ppm	1.7	31
Hydrogen sulfide emission, lb/hr	0.2	3.2
Sulfur dioxide concentration, ppm	0.14	0.45
Sulfur dioxide emission, lb/hr	0.03	0.09
Other organic sulfur concentration (as SO_2), ppm	0.21	-
Other organic sulfur emission (as SO_2), lb/hr	0.04	-
Particulate concentration, gr/ft^3	0.57	0.17
Particulate emission, lb/hr	100	30

Sampling of relief gases generated during the cooking process was not undertaken.

Smelt (Dissolving) Tank

The smelt tank stack is equipped with a water spray to reduce emission of material to the atmosphere. Samples were obtained immediately under the spray and as such probably represent final emission to the atmosphere. Results of the two sampling runs performed with the University of Florida sampler are summarized in Table 16. These emissions are not of major significance when compared to emissions from other sources.

Lime Kiln

Emissions from lime kilns consist of particulates. hydrogen sulfide, and sulfur dioxide. The particulate consists largely of lime dust, with lesser amounts of sodium salts. Values reported in the literature are given below to indicate relative composition of the emission.

Particulate	Loading, gr/ft^3
Calcium carbonate	4 - 20
Sodium carbonate	1.5 - 2.5
Sodium sulfate	0.1 - 0.3

The lime kiln at the paper mill is equipped with a water spray to reduce emissions. Measurements of lime kiln emissions were made after the water sprays and, as such, represent emissions to the atmosphere. A summary of emissions data is given in Table 17. The sulfur dioxide derives from the Bunker C fuel used to heat the kiln. Hydrogen sulfide and particulates derive mainly from the kiln feed.

Emissions of sulfur dioxide and hydrogen sulfide from the lime kiln are minor. Emissions of particulates are of the same

Table 17. EMISSION FROM LIME KILN

Emission	Run 1	Run 2	Run 3	Run 4	Average
Gas temperature, °F					185
Gas velocity, fpm					720
Gas emission, cfm					21,600
Hydrogen sulfide, ppm	86	-	-	-	86
Hydrogen sulfide, lb/hr	9.7	-	-	-	9.7
Sulfur dioxide, ppm	1.7	4.4	-	-	3.7
Sulfur dioxide, lb/hr	0.35	0.93	-	-	0.64
Particulate, gr/ft^3	0.25	0.54	0.57	0.93	0.57
Particulate, lb/hr	46.3	100.0	105.5	172.1	106

magnitude as those from the recovery furnace. At the time of this test, particulate emission from the kiln was judged visually to be less than normal. Thus from this observation and the difference in height of particulate release, the lime kiln represents a greater source of particulate pollution than the recovery furnace. At times, emissions from the kiln are of Ringelmann 4 or 5[28] and, as such, contribute to the over-all soiling of the air.

SULFITE PULP MILL

Sulfite pulp is produced at The Brown Company by a magnesium-base pulping operation. Raw materials used in making the pulping liquor are sulfur dioxide (produced from burning sulfur) and magnesium hydroxide (produced by slaking magnesia). Recovery of cooking chemicals is an integral part of this process, as in the kraft process. Sources of pollutant emission are many, and include the digesters, blow system, various vents in the processing of the pulp, preparation of the sulfur dioxide and vents on the acid towers, the start-up stack, and the final stack in the recovery of the boiler gas (the MGO stack).

MGO Stack

Strong liquor from the evaporators is burned in the boilers to produce steam and recover the cooking chemicals. The hot flue gas from the boiler contains 0.8 percent sulfur (56 tons/day SO_2). This gas is passed sequentially through the cooling tower, heat exchanger, liquid scrubber, entrainment separator, liquid scrubber, and packed tower separator, and then is discharged to the atmosphere through the MGO stack. A start-up stack prior to the cooling tower discharges the flue gas directly when the system is initially started.

Six runs were made for sulfur dioxide and particulate. Results are given in Table 18. Particulate emission is negligible. The sulfur dioxide emission is of major proportion. In runs 1 through 4, the capacity of the collection device was exceeded and these runs are discounted. The sulfur dioxide emission is certainly excessive; whether large amounts are continually emitted or whether this represents an out-of-balance condition cannot be answered without further sampling. Measurements were made on two separate days; personal experience of the investigators on two other occasions when the MGO plume descended to breathing level suggests that high sulfur dioxide levels are not unusual.

Table 18. EMISSIONS FROM MGO STACK

Emission	Run 5	Run 6
Gas temperature, °F	105	105
Gas velocity, fps	28	28
Gas emission, cfm	55,000	55,000
Sulfur dioxide, ppm	3,765	3,355
Sulfur dioxide, lb/hr	2,040	1,800
Particulate, gr/ft^3	neg.	neg.

Based on process data, sulfur dioxide emissions from the start-up stack are estimated at 16,000 ppm and 4,670 pounds per hour.

OTHER PROCESS EMISSIONS

Other processes carried on at The Brown Company include manufacture of Solka-floc, Bermico pipe, Onco insoles, and eletrolytic chlorine. Emissions from these sources do not seem of major significance, and no measurements were made on the emissions.

BOILER PLANT (HEINE PLANT)

Ten boilers with a combined capacity

Table 19. SUMMARY OF PERTINENT INFORMATION ON BOILERS

Boiler No.	Fuel[a]	How fired	Percent time operated[b]	Coal used, tons[c]	Capacity, lb/hr
1	-	underfeed	0	0	53,000
2	hard	chain grate	48	3,258	45,500
3	hard	chain grate	36	3,361	60,600
4	hard	chain grate	5	158	60,600
5	soft	pulverized	11	450	56,800
6	soft	pulverized	96	11,993	90,600
7	soft	pulverized	83	16,722	120,800
8	black liquor	kraft recovery	-	-	90,000
9	soft	pulverized	95	47,510	225,000
10	red liquor	MGO recovery	-	-	149,500

[a]Hard and soft refer to coal as fuel; analysis of these coals is given in Table 18.
[b]From November 29, 1959, to July 9, 1960.
[c]From November 29, 1959, to July 9, 1960.

Table 20. ANALYSIS OF COAL USED IN HEINE PLANT

Type	Soft	Hard
Moisture, %[a]	1.3	1.2
Volatile, %	34.6	17.9
Fixed carbon, %	56.2	71.9
Ash, %	8.0	9.2
Sulfur, %	0.8	0.9
Btu/lb	13,700	13,600

[a]Coal is about 0.5 percent moisture, as burned.

Table 21. COAL USAGE IN TONS AT HEINE PLANT

Period	Soft coal	Hard coal	Total coal
Nov 29 to Dec 26, 1959	11,316	1,588	12,904
Dec 27, 1959 to Jan 23, 1960	11,099	1,778	12,877
Jan 24 to Feb 20, 1960	10,417	990	11,407
Feb 21 to Mar 19, 1960	10,932	1,416	12,348
Mar 20 to Apr 16, 1960	10,297	655	10,952
Apr 17 to May 14, 1960	8,315	56	8,371
May 15 to June 11, 1960	7,006	263	7,269
June 12 to July 9, 1960	7,011	30	7,041
Total for 8 periods	76,393	6,776	83,169
Total extrapolated to year	124,520	11,045	135,565

Table 22. ESTIMATED PARTICULATE EMISSIONS FROM HEINE BOILERS

Boiler	lb/hr	lb/yr
1	0	0
2	35	147,000
3	48	151,000
4	16	7,000
5	91	88,000
6	279	2,346,000
7	450	3,271,000
9	1,120	9,313,000
Total		15,323,000

Table 23. ESTIMATED EMISSION OF SULFUR GASES FROM HEINE BOILERS IN POUNDS PER HOUR

Boiler	Sulfur dioxide	Sulfur trioxide	Hydrogen sulfide
1	0	0	0
2	38.9	4.7	0.091
3	53.4	6.5	0.125
4	18.1	2.2	0.041
5	20.2	2.8	0.047
6	61.8	7.5	0.144
7	99.7	12.1	0.232
9	248.0	30.2	0.578

Table 24. ESTIMATED TOTAL EMISSIONS OF SULFUR GASES FROM HEINE BOILER IN POUNDS PER YEAR

Boiler	Sulfur dioxide	Sulfur trioxide	Hydrogen sulfide
1	0	0	0
2	163,570	19,850	383
3	168,740	20,490	394
4	7,940	960	18
5	19,510	2,380	46
6	519,990	63,340	1,213
7	725,040	88,310	1,690
9	2,064,280	251,440	4,812
Total	3,669,070	446,770	8,556

of 952,400 pounds of steam per hour supply the paper mill with process steam, heating steam, and steam for running five turbines. Pertinent information on the boilers is given in Table 19. Boilers number 1 through 7, and 9 comprise the boiler plant. Boiler number 8 is the kraft recovery furnace and boiler number 10 is the MGO recovery furnace, considered integral to the sulfate and sulfite mills respectively.

The boiler number 9, which is the largest and newest of the boilers, is run almost continuously at constant load. Boilers 6 and 7 are also operated most of the time and are used to swing the load on fluctuating steam demands. The other boilers, 2 through 5, are used to meet increased steam demands, particularly during the colder months. Boilers 5, 6, 7, and 9 use pulverized soft coal for fuel; 2, 3, and 4 use chain grate stokers and hard coal. A composite analysis of coal used in the Heine plant is given in Table 20.

Some 135,000 tons of coal, of which 125,000 are soft coal, are burned annually. The amount of coal burned varies over the year (Table 21), being greater in the winter and lower in the summer. Part or most of this difference may be attributed to increased steam needs

during the colder months. An unknown portion may reflect changes in production; the mill was operating considerably below capacity at the time of this survey (summer, 1960).

From combined information on fuel usage, fuel analysis, amount of time operated, firing means, and emission factors (Appendix B), estimates were made on emissions from the boilers (Tables 22 through 24). The emission figures on sulfur gases and nitrogen oxides are probably close to actual emissions; the estimates on particulates are high, since they do not include reduction brought about by control equipment.

Particulate Emissions

Boilers 6, 7, and 9 are equipped with cyclone or multiple small-diameter cyclones to reduce emission of particulates. Four tests were made on boiler 9 and one on boiler 6 to establish particulate emissions under steady operating conditions. Results of these tests are summarized in Table 25 (also see Figure 7). Boiler 6 operating at 55 percent of capacity emitted 60 pounds of particulate per hour. Boiler 9 operating at 70 percent of capacity emitted 520 pounds per hour. Particulate loading was 0.20 grain per cubic foot for boiler 6 and 0.38 grain per cubic foot for boiler 9, at stack conditions. With these loadings calculated at standard conditions (32°F, 1 atm), these values become 0.31 grain per standard cubic foot for boiler 6 and 0.70 for boiler 9. Emissions from boiler 6 were within limits generally specified in ordinances; emissions from boiler 9 exceeded such limitations by about a factor of 2. Since these tests were run while the boilers were operating under steady load and at reduced steam demand, it may be anticipated that emissions under normal operating conditions will exceed these test values.

If the measured particulate emissions (extrapolated linearly to full capacity operation of the boilers) are compared to the estimated emissions (Table 22), the ratio of measured to estimated is 0.40 for boiler 6 and 0.65 for boiler 9. In estimates of the over-all contribution of the Heine boilers to the air pollution problem, therefore, these factors were applied to particulate emissions given in Table 22 (see Table 27).

Dense Smoke

Two days of the survey were devoted to observing smoke emissions from the boiler plant. Emissions were evaluated by means of the Public Health Service smoke inspection guide[28] and expressed as Ringelmann number. Table 26 summarizes these readings. Cumulative frequency observations are given in Figure 2. From these observations and from casual observations made during the entire study, it is evident that boilers 6 and 7, which were used to swing the load in steam demand, are operated poorly and emit excessive amounts of dark smoke. If smoke darker than Ringelmann number 2 is considered excessive (the usual ordinance limitation), then boiler 6 operated satisfactorily about one-third of the time.

Sulfur Gases

Combustion of coal releases sulfur

Table 25. SUMMARY OF MEASURED PARTICULATE EMISSIONS FROM HEINE BOILERS

	Boiler 6[a]	Boiler 9[b]			
		Run 1	Run 2	Run 3	Run 4
Gas temperature, °F	288	414	414	405	405
Gas velocity, fps	46.9	98.2	98.2	96.5	96.5
Gas emission, cfm	35,000	165,600	165,600	150,000	150,000
Particulate concentration, gr/ft^3	0.20	0.44	0.30	0.41	0.39
Particulate emission, lb/hr	60	625	425	528	502

[a]Boiler 6 operating at 55 percent of capacity.
[b]Boiler 9 operating at 70 percent of capacity.

Table 26. SMOKE OBSERVATIONS ON HEINE BOILERS

Boiler	Date	Number of Hours Read	Number of Readings Made	Average Ringelmann Number
6	Aug 10	5	30	2.5
9	Aug 10	5	25	0.5-1.0
9	Aug 11	9	81	1.0-1.5
7	Aug 11	1	15	1.5
6	Aug 11	9	125	2.5

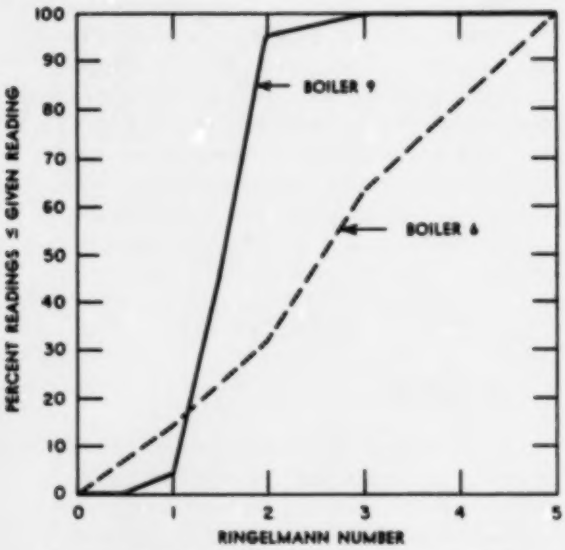


Figure 2. Cumulative frequency distribution. Smoke emission from boilers no. 6 & 9.

dioxide, sulfur trioxide, and hydrogen sulfide to the atmosphere. Under conditions generally prevailing in industrial steam-raising equipment, these gases are generally emitted in the ratio of 430:50:1, respectively. Approximately 97 percent of the sulfur is emitted; 3 percent is retained. The sulfur content of coal burned at the boiler plant runs about 0.8 percent. Estimations of the emission of sulfur gases are given in Tables 23 and 24. Somewhat over half (56 percent) of these sulfur gases come from number 9 boiler. The amount of hydrogen sulfide emitted is negligible. The amount of sulfur dioxide and trioxide may result in undesirably high short-term concentrations, because of the relatively low levels at which they are released.

Summary of Boiler Emissions

Estimated emissions from the Heine plant are summarized in Table 27. The pollutants of most interest are particulates, sulfur dioxide, and sulfur trioxide. The other pollutants in the amounts indicated are of little concern.

Table 27. SUMMARY OF ESTIMATED EMISSIONS FROM HEINE BOILERS

Pollutant	lb/yr	Avg lb/hr
Particulate	8,550,000	975
Sulfur dioxide	3,669,070	420
Sulfur trioxide	446,770	50
Hydrogen sulfide	8,560	1
Nitrogen dioxide	2,711,310	310
Hydrogen chloride	542,260	60
Hydrogen fluoride	54,230	6

SUMMARY OF INDUSTRIAL POLLUTANTS

Primary industrial emissions include hydrogen sulfide, sulfur dioxide, other reduced-sulfur compounds, particulates, odors, and dark smoke. These emissions are summarized in Table 28. The major source of hydrogen sulfide is the recovery furnace. The major source of sulfur dioxide is the MGO stack; a source of lesser amounts is the boiler plant. The major source of particulates and dark smoke is the boiler plant; the recovery furnace and lime kiln are additional sources. Odors originate in various places in the kraft process, and also in the sulfite process but to a lesser degree. Sulfur trioxide, mainly from the boiler plant, may be of importance in combination with the sulfur dioxide. Other industrial emissions are of little importance.

CONCLUSIONS ON NATURE OF POLLUTION

The potential emissions of certain

Table 28. SUMMARY OF SELECTED INDUSTRIAL EMISSIONS

Source	Emissions, lb/hr			Other emissions
	Hydrogen sulfide	Sulfur dioxide	Particulate	
Recovery	330	50	100	odor
Blow system	6	1	0	odor
Smelt tank	2	0	65	
Lime kiln	10	1	100	occasional smoke
MGO stack	0	1900	0	
Heine plant	1	400	1000	dark smoke

Table 29. COMPARISON OF EMISSIONS FROM VARIOUS SOURCES IN POUNDS PER YEAR

Pollutant	Domestic fuel consumption	Automobiles	Industrial fuel consumption	Industrial processes	Total
Particulate	169,000	50,000	8,930,000	2,320,000	11,089,000
Sulfur oxides	1,811,000	40,000	4,043,000	22,830,000	28,724,000
Nitrogen oxides	771,000	525,000	2,711,310	-	4,007,000

classes of pollutants from the general sources considered are summarized in Table 29. From these estimates, the major source of particulates may be tentatively ascribed to industrial fuel combustion and that of sulfur oxides to industrial process emissions. The pollutants of concern in Berlin include particulates, sulfur oxides, hydrogen sulfide, and odorous reduced-sulfur compounds. The general emission figures indicate that other pollutants are of lesser importance. The general (excluding health) effects that may be anticipated from pollution emissions of this type are soiling by particulates, sulfur dioxide damage to vegetation, and malodors. Emissions of this magnitude, which may be confined in the relatively small volume bounded by the valley walls and a low-level inversion, could conceivably be of community-wide concern under adverse weather conditions.

TRANSPORT AND DISPERSION OF POLLUTION

The degree to which pollutants accumulate is largely dependent upon the weather. Thus, concentrations of local air pollutants may vary markedly even though the total discharge of pollutants remains relatively constant. Weather factors that have a pronounced effect on air pollutant concentrations are: wind speed and direction; stability, or more generally the resistance to vertical motion of the lower layers of air; and humidity and condensation forms, particularly fog.

Transportation and dispersion of pollutants are essentially proportional to wind speed (see Figure 9). Generally speaking, the greater the wind speed, the greater the dispersion of air-borne wastes. Wind direction and its variability plays an important role in the directional transport and lateral spreading of these wastes.

Stability plays an important role in the relationship of meteorology to air pollution potential. Temperature change with height determines the static stability of the atmosphere. Temperature normally decreases with height in the atmosphere. The rate of decrease of temperature with height is called the lapse rate. The smaller the lapse rate, the less the vertical mixing. When temperature increases with height (negative lapse rate), an inversion condition exists and vertical mixing is very much restricted. Shallow inversions based at or near the earth's surface may be produced nightly when the sky is clear and the wind is light. This type of inversion usually breaks up in the late morning. If the intensity and vertical extent of the inversion are great enough, solar heating during the day may be insufficient to cause a break-up of the inversion.

The role of humidity, including condensation in the form of drizzle, snow, and rain, is less direct that that of wind and stability. Condensation forms may have a direct effect by "rain out" (removal of gaseous and particulate material during precipitation). Fog usually limits solar heating, and thereby adversely affects the degree of vertical diffusion in the lower layers of air. Air pollution, on the other hand, may have a direct effect on weather by

providing condensation nuclei for the formation of fog.

In investigations of known air pollution episodes, all three of these weather elements have been identified as contributors to the accumulation of abnormally high concentrations of pollution. The simultaneous occurrence of light winds, stable conditions, and fog for brief periods is not particularly a rare phenomenon, especially in hilly country. Experience has suggested that such conditions must persist for several days before abnormally high concentrations occur. These periods are usually associated with the prolonged stagnation of high pressure systems.

Major air pollution episodes are usually related to the incidence of stagnating anticyclones in or near urban areas for protracted periods (four days or more). During such periods surface wind speeds may become insufficient to carry away the accumulation of pollutants, thereby causing distressful and possibly hazardous conditions for the local inhabitants.

TOPOGRAPHY

Berlin is located in the White Mountains about 15 miles north-northeast of the summit of Mount Washington. The city is situated on the floor and at the apex of a Y-shaped valley system, which is the junction of the Androscoggin and Dead Rivers, the main valley being the Androscoggin, (Figures 3 and 4). The floor of the entire valley system slopes gradually downward toward the south, and in the city the valley floor is 1000 feet above sea level. The sides of the Androscoggin River valley north of Berlin slope upward rather sharply to Cates Hill (1900 ft MSL) (A)* on the northwesterly side and more gradually on the sourtheasterly side to Bald Cap (3090 ft MSL) (B). The Dead River Valley is bounded sharply by Cates Hill on the

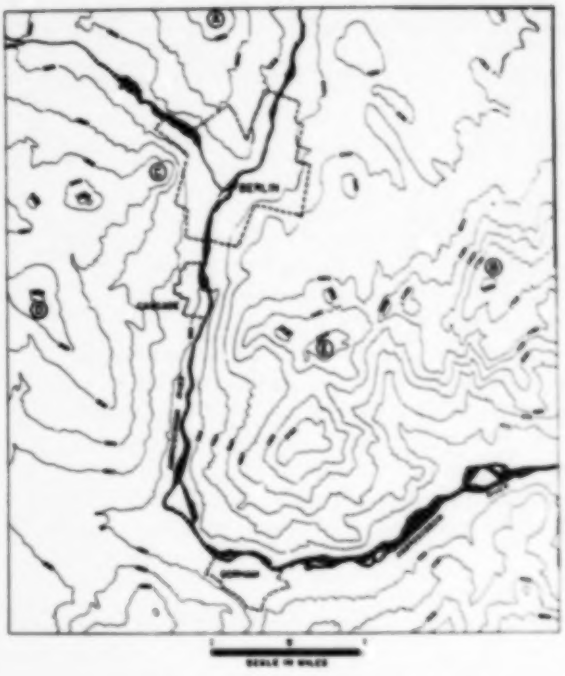


Figure 3. Topography of Berlin area, south.

northeasterly side; a cliff with a talus base, Mount Forest (2046 ft MSL) (C), forms the southwesterly wall. The valley extension to the south has rather well-defined uniform slopes on both sides with Sugar Mountain (2465 ft MSL) (D) to the west and Cascade Mountain (2500 ft MSL) (E) to the east. The slopes are primarily tree-covered with the exception of the lower 500 feet of the south side of Cates Hill, which is in the urban area. There are open fields along the valley floor to the north. The well-defined valley system tends to isolate air flow in the valley from the broad scale air flow over the area, particularly during stable atmospheric conditions. A physiographic diagram of the Berlin area is shown in Figure 5.

CLIMATOLOGY

The Berlin area has a continental-type climate, which is manifested by larger annual and diurnal temperature variations than occur in a coastal loca-

* Letters A through E denote topographic features in Figures 3 and 4.

Figure 4. Topography of Berlin area, north.

tion. The area is in the "prevailing westerlies," a belt in which the air aloft moves eastward. This upper air generally controls the movement of synoptic pressure patterns near the surface. This is also a preferred area for the passage of low pressure systems that originate to the west and move eastward;[22] storm systems with changes in air mass (e.g., temperature, moisture, and wind), which are frequently very abrupt, occur relatively often, especially during the winter and spring months. On the average, there are frontal passages every 3 to 4 days. Fair weather with slow change occurs most often during the summer and fall months. Precipitation, however, is rather uniformly distributed throughout the year. Most of the precipitation in the colder months is associated with frontal or low pressure storm systems. When this storm activity ebbs during the warmer part of the year, thunderstorm activity increases.

Atmospheric stability and wind speed are important parameters affecting the dispersion characteristics of air pollution emissions. Stability is inversely related and wind speed is directly related to dispersion. No climatological data on these parameters are available for Berlin, but data from nearby locations can be used to give an idea of the relative seasonal changes. The annual variation of wind speed for three locations in this region is shown in Figure 6. All of these locations show the same general trend, namely, higher speed in winter and lower speed in summer. The mean wind speeds at Berlin are expected to resemble more closely those for Concord, New Hampshire, because of terrain characteristics. The percent of nights with stable atmospheric conditions (indicated by inversions based below 500 ft) are 55, 65, 80, and 70 for winter, spring, summer, and fall, respectively, at Burlington, Vermont.

How do these climatological features affect the air pollution potential of the area? During the winter and spring seasons when storms are more frequent, winds are stronger and the air is more unstable and turbulent. Consequently, these seasons have a lower air pollution potential. On the other hand, during the summer and fall seasons the frequency of storms is reduced, resulting in lighter winds and a more stable atmosphere, and therefore, the air pollution potential is higher. Also, according to a study by Korshover,[23] during September and October stagnating anticyclones, which persist in this area for 4 or more days, occur once every 5 years, on the average. A stagnating anticyclone is a quasi-stationary region of high pressure in which the winds are light and the atmosphere is stable, sometimes with an inversion persisting aloft, thus making it possible for pollutants to accumulate in the lower layers of the atmosphere over long time periods.

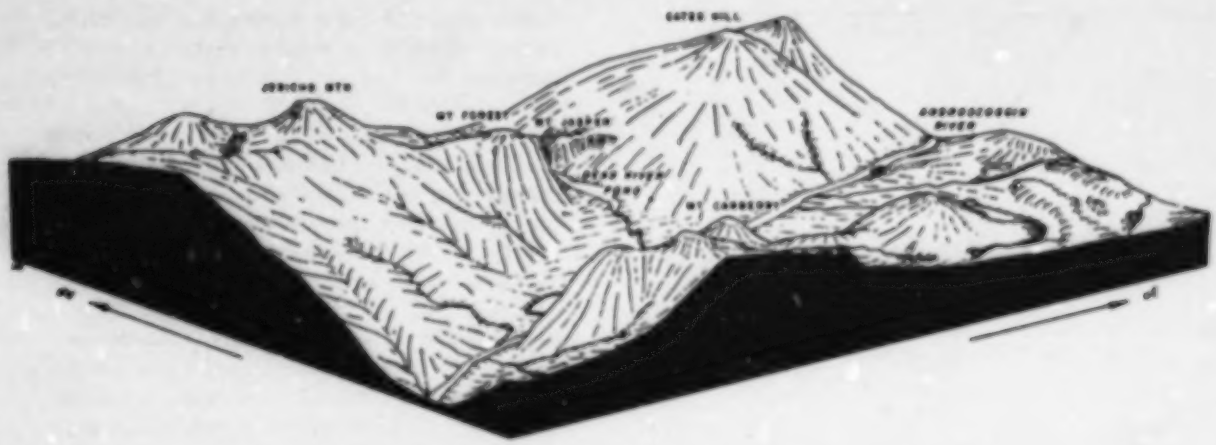


Figure 5. Physiographic diagram of Berlin area. Vertical exaggeration 2 times.

Temperature is an indicator of potential air pollution source strength in the form of heating degree-days,* which are a determinant in home and industrial heating requirements. The normal annual temperature variation is shown in Figure 7. Berlin, on the average, has a comparatively high number of degree-days, because of its geographical location and resultant large annual temperature variation.

LOCAL METEOROLOGY

For the study period, two wind instruments, which continuously record both wind direction and speed, and two hygrothermographs were installed near the junction of the valleys (Figure 1). The wind was measured 55 feet above ground level at locations A and C, and the temperature was measured 6 feet above ground level at locations A and B. These locations were selected as carefully as possible so that a reasonable representation of local wind and temperature features could be estimated with a limited amount of meteorological equipment.

* Heating degree-days are the number of degrees that the daily mean temperature is below the base of 65°F. Values of this parameter are usually summed over a month or season.

For the period from July 26 to October 1, the hourly mean wind direction frequencies were analyzed (Figure 8). In the figure the lengths of the bars are proportional to the frequencies of occurrence of the various wind directions. It can be seen that the wind direction is decidedly channeled by the valley at both locations.

The air movement in the valley is controlled by the synoptic weather situation and the local topography. The degree of topographic influence varies with atmos-

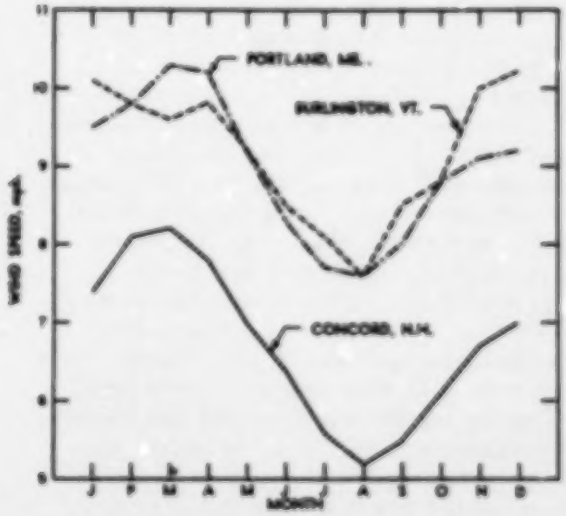


Figure 6. Monthly mean wind speeds. Selected New England locations. [43]

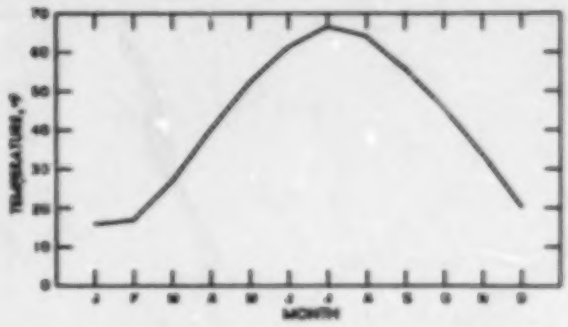


Figure 7. Monthly mean temperatures - Berlin, N.H. [42]

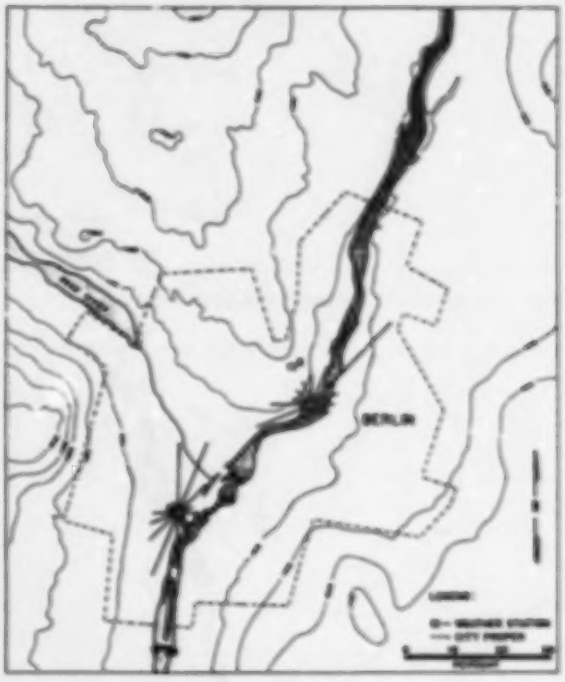


Figure 8. Hourly mean wind direction frequencies.

pheric stability; the more stable the atmosphere becomes, the more unrelated the air flow in the valley is to the broad scale air flow over the area. During stable atmospheric conditions, the air flow near the surface in the valley is primarily determined by local differences in temperature. Cooler, more dense air tends to flow toward warmer, less dense air. In the absence of solar radiation, air on the slopes of the hillsides cools and becomes more dense than the surrounding air. This induces an air flow down the hillsides. With solar radiation present the air on the slopes is generally warmer than air at the same height in the free air, thereby inducing an air flow up the hillside. Urbanization also influences the air flow because the urban area is a heat source. The air temperature over the city is higher than over the surrounding areas, and thus air flows near the surface towards the city. The depth of these local flow patterns varies, and at times the air flow aloft is in the opposite direction from the air flow near the surface.

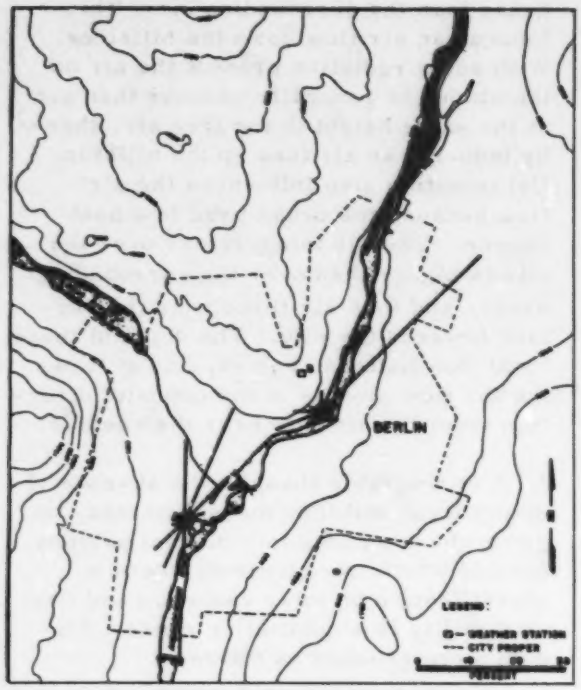
It is desirable then, in the absence of direct local stability measurements, to group the wind data into diurnal periods, each of which is representative of a classification of solar radiation and thus of stability in a qualitative sense. The data were grouped as follows:

1. Night (2200-0600 EST) - characterized by maximum low-level stability with pollutant dispersion at a minimum. Pollutants tend to remain at or near the height at which they are emitted. The larger and more dense particles will, of course, tend to settle out, even under extremely stable conditions.

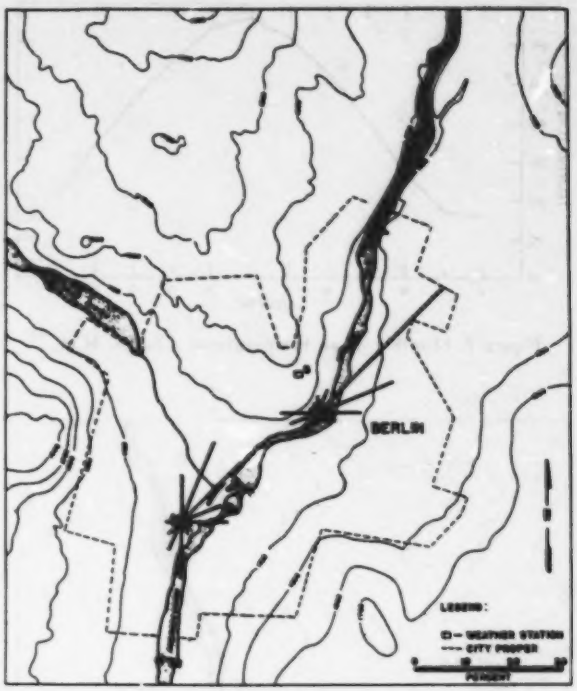
2. Morning Transition (0600-0900 EST) - characterized by instability, with mixing near the ground and stability aloft. Pollutants that were emitted at higher levels during stable conditions along with current emissions fumigate the ground level by convection. Thus, ground level concentrations are usually high.

3. Day (0900-1800 EST) - characterized by maximum instability and maximum dispersion of pollutants.

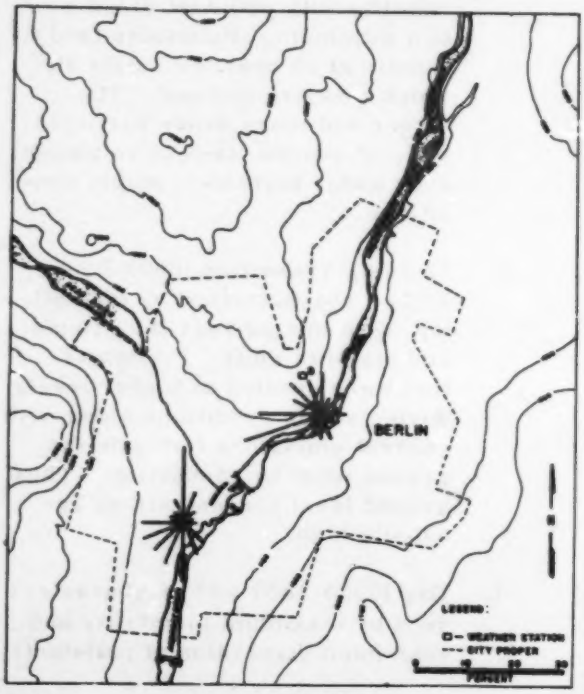
4. Evening Transition (1800-2200 EST) - characterized by the



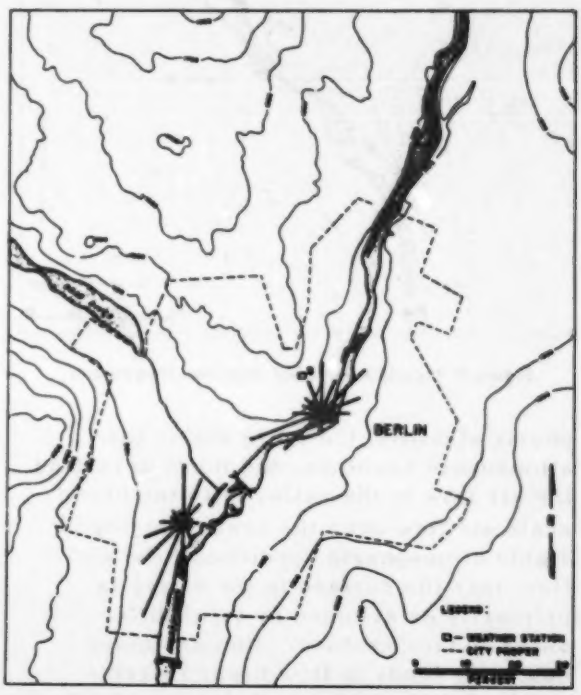
(9a) NIGHT (22-06 EST)



(9b) MORNING TRANSITION (06-09 EST)



(9c) DAY (09-18 EST)



(9d) EVENING TRANSITION (18-22 EST)

Figure 9. Hourly mean wind direction frequencies and diurnal variation.

changeover from unstable to stable conditions, with the air becoming more stable near the ground level first. This more stable layer becomes deeper and deeper with time. This causes the pollutants emitted near the ground level to remain near the ground and the pollutants emitted at higher levels to disperse at a relatively rapid rate until the stable layer envelops these high-level emissions also.

The results of the diurnal wind direction analyses are shown in Figure 9. During the night period air shows a distinct preference to flow down the valley; however, the down-valley flow with stable conditions at location C usually commences 2 hours before the down-valley flow at location A. This temporary interruption of the down-valley flow is caused by the warmer city air reversing the temperature gradient along the valley axis. In the morning transition period, the preference is still for general down-valley flow but with more of an easterly cross-valley component than at night, indicating that the air is starting to move upslope on the western sides of the valley boundaries. Early morning solar heating of the eastward-facing sides causes air flow toward this warmer area. During the day the flow is generally up-valley but is not as persistent as the down-valley flow at night because there is more of a tendency for the air to flow cross-valley in either direction. This results from the instability of the valley air during the daytime. Its turbulent mixing enhances the probability of its flowing in the same direction as the air at higher levels over the valley. The evening transition period also shows a general up-valley flow with a slight tendency for the air to flow cross-valley from the westerly side of the valley. The up-valley flow tendency is caused by the prevailing wind direction aloft and the valley orientation, but the cross-valley winds are caused primarily by local temperature differences -- the eastward-facing hillside usually cools before the westward-facing hillside.

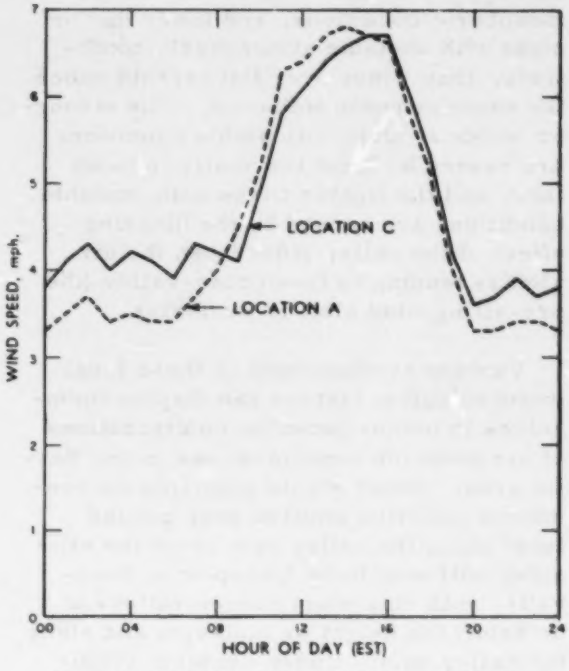


Figure 10. Diurnal variation of wind speed - Berlin, N.H. - July 26 - Sept. 30, 1960.

The wind data in Figure 17 represent only the summer period. The air, as indicated before, is less stable during winter and spring. Because the air is more unstable and therefore more turbulent during these seasons, the frequency of local, thermally induced, diurnal airflow variations is decreased and the air flow in the valley tends to follow more closely the air flow aloft, with only orographic barriers disrupting the flow.

Wind speed is an indicator of atmospheric dispersion because the higher the speed the greater the turbulence generated. Also, initial dilution of air pollution emissions is directly related to wind speed. On the average the wind speed in Berlin is highest during the daylight hours and lowest at night (Figure 10). Generally, wind speeds near the surface in the valley are higher at night with stable at-

mospheric conditions, and lower day or night with unstable atmospheric conditions, than winds over flat terrain under the same synoptic influence. The stronger winds at night with stable conditions are caused by local thermally induced flow, and the lighter winds with unstable conditions are caused by the blocking effect of the valley sides when the air aloft is tending to flow cross-valley (the prevailing wind aloft is westerly).

Various combinations of these local meteorological factors can display themselves in unique potential configurations of air pollution concentrations in the Berlin area. Under stable atmospheric conditions pollution emitted near ground level along the valley axis or on the hillsides will tend to be transported down-valley with maximum concentrations at or below the height or emission and along the valley axis. Under unstable conditions, however, the transport of pollutants is not as well defined. It can be either up- or down-valley and sometimes even cross-valley, depending on the direction of the air flow aloft. During these unstable conditions, however, pollution is diffused rather rapidly throughout the valley. Hence, there is a tendency for air pollution concentrations to be at least as high along the hillsides as along the valley floor. With a cross-valley transport component the hillside concentrations downwind from sources can be extremely high for short periods of time. Persistent cross-valley transport components usually occur only in the morning and evening transition periods. During the morning period the component is predominantly from the east and therefore the western hillside locations can experience maximum concentrations for periods of 2 hours or more under fumigation-type stability conditions. The cross-valley component is generally reversed during the evening period but is not as persistent as in the morning. Also, during all types of stability conditions there is a rather persistent convergence, of air flow near the surface over the city. Because of this convergence, some of the air is forced to rise, resulting in more rapid dispersion of air pollution emissions over the urban area.

AIR QUALITY

The air sampling network has been described earlier, and is depicted in Figure 1. Nine stations were operated during August and September; three of these were operated from August, 1960, through May, 1961. Two additional stations were established at Community Field and St. Louis Hospital.

COMMUNITY FIELD STATION

This station was established at Unity and Mason Streets; sampling was conducted for suspended particulates, soiling, sulfur dioxide, and hydrogen sulfide.

Particulate Levels

Average particulate level for the 2-month period was 183 micrograms per cubic meter, with a minimum of 56 and a maximum of 309. Standard deviation of the data is 70. Figures C1 and C2 (Appendix C) show particulate levels versus date and cumulative frequency distribution for the data. A comparison of these levels with levels reported by the National Air Sampling Network (Table 30) for other areas shows that the levels encountered

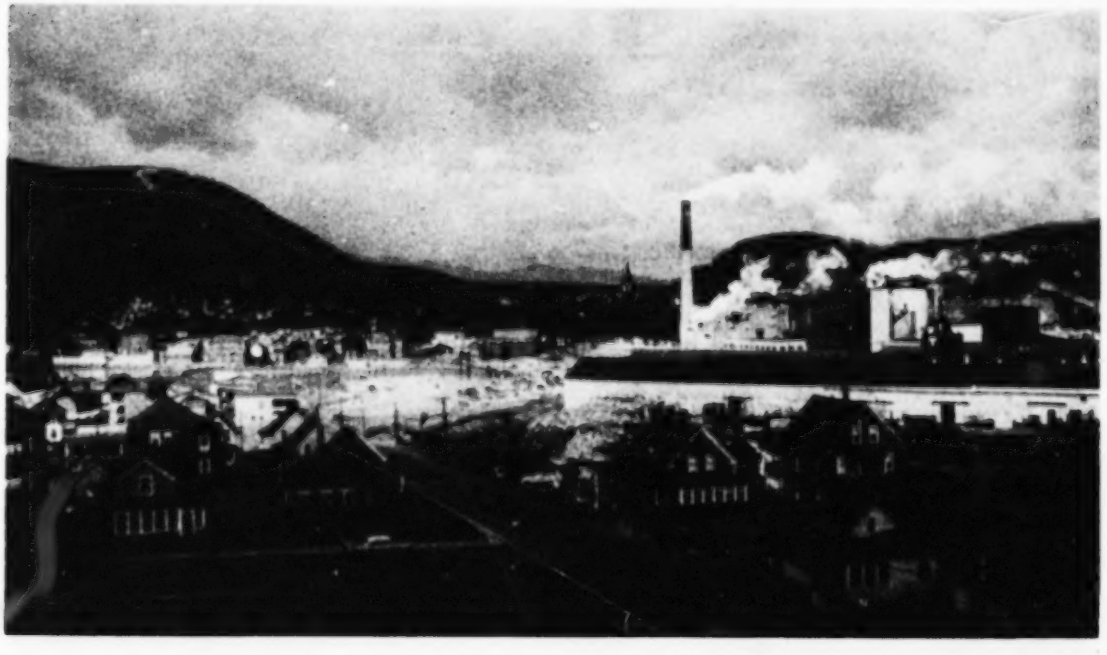
Table 30. COMPARISON OF PARTICULATE LEVELS FOR VARIOUS PLACES[39]

Place	Particulate Levels, $\mu g/m^3$		
	Average	Maximum	Minimum
Rural Vermont	32	62	15
Non-urban U. S.	40	460	3
New Hampshire	70	152	4
U. S. Cities of <50,000 People	81	-	-
New England	118	472	11
Urban U. S.	163	3112	9
Berlin	183	309	56

General View of Berlin, New Hampshire.

View from Susan Street Playground.

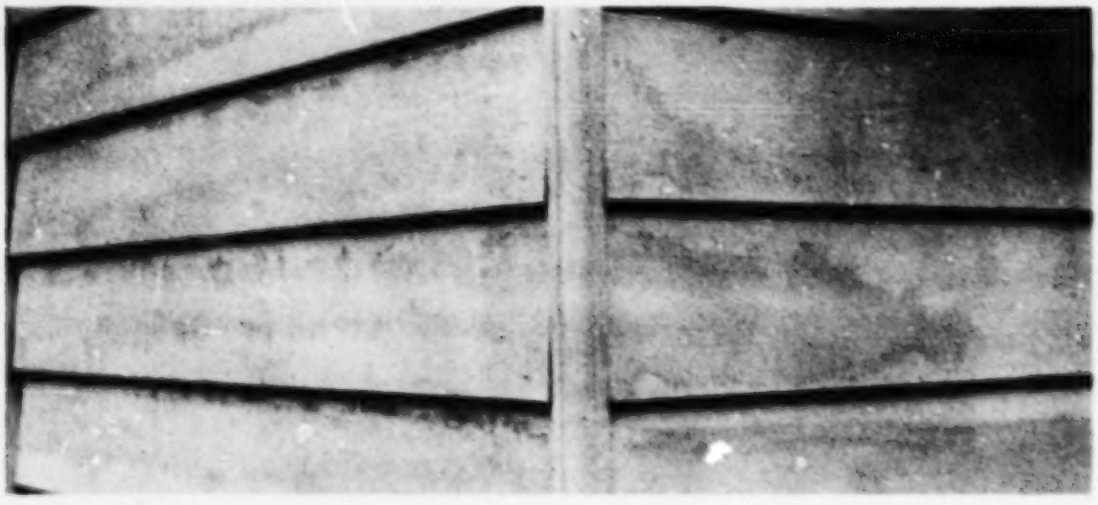
Break up of morning inversion. Lower level emissions below inversion level are moving down valley. Upper level pollution moving in oposite direction.



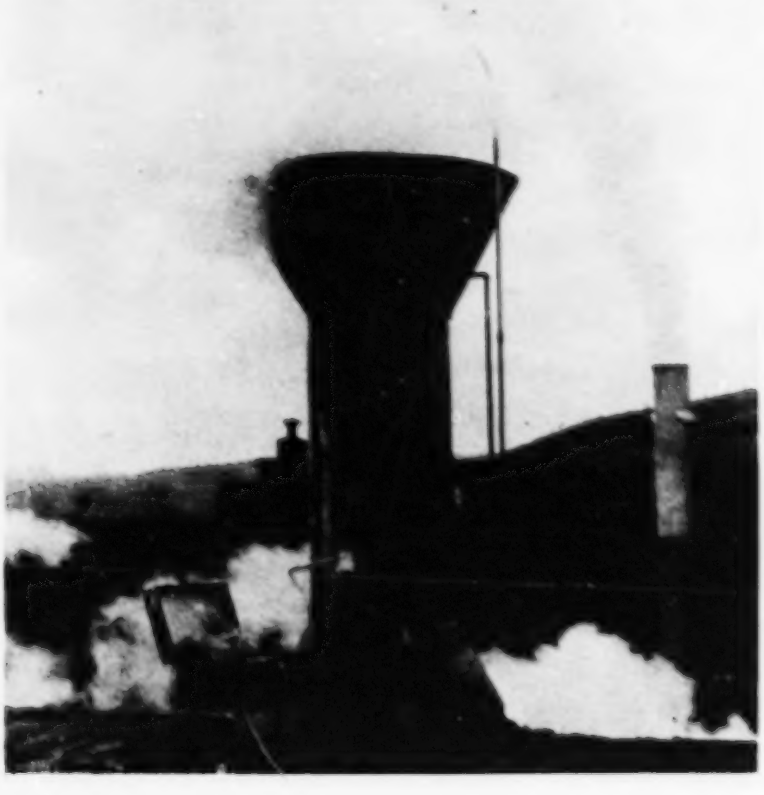
View from Angel Guardian School toward Dead River. Downtown area is in left center.

Vicinity of Community Field.

Heine boilers showing emissions from boilers 6 & 9.



Paint damage to house.



Use of stack sampler on smelt tank stack. MGO stack in right background.

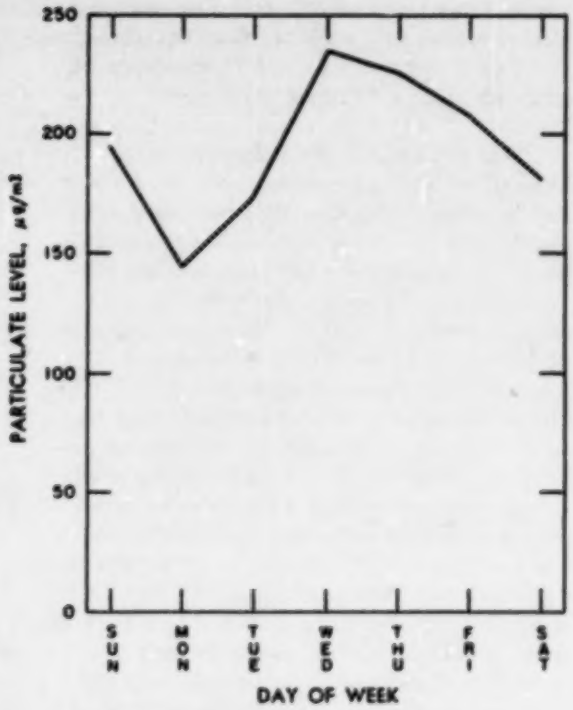


Figure 11. Particulate levels vs. day of week.

in Berlin are very high. Such comparisons are of limited value, however, because the location of the sampler markedly influences the sample collected. The low value of standard deviation indicates that extremely low or high particulate levels are not likely.

Average particulate levels show a minimum on Monday, with a rapid increase to a maximum on Wednesday, and then a general decline through Monday (Figure 11). Statistical analysis of the data, however, indicates that no significant difference exists in particulate levels for any day of the week. This is not in keeping with the generally established finding that weekends are "cleaner" than weekdays in large communities. This finding of no significant day-of-week variation in particulate levels does support the contention that the major source of pollution is the paper mill, since this mill operates on a continuous basis.

Soiling

The average soiling index for the 2-month period was 0.5 Cohs per 1000 linear feet, with a maximum value of 1.9 for a 2-hour period. These levels of soiling are considered light.

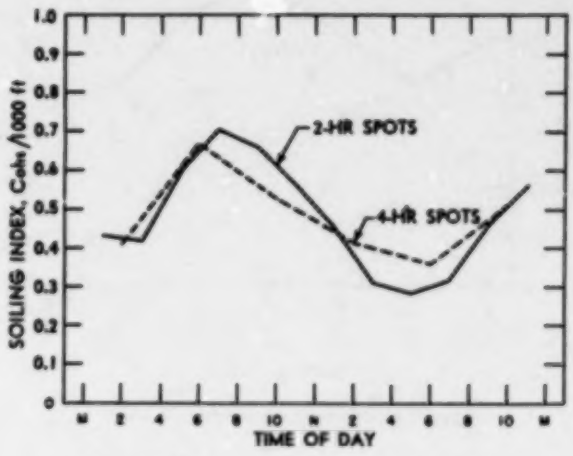


Figure 12. Diurnal variation of soiling index.

In view of the fact that the particulate level is relatively high, some question may arise as to why the soiling index appears low. A major portion of this difference may be ascribed to the size of particulate sampled by each of these methods. The hi-vol sampler used to sample "suspended particulates" collects particles of 100-microns diameter and less; the A.I.S.I. used to sample "soiling characteristic" collects particles of 7-microns diameter and less (as used here). Hence, if the majority of particles present had diameters of 10 microns or greater, particulate levels would be high but measured soiling levels would be low. If this were the case, it should be anticipated that (1) source emissions would consist largely of larger-sized particles, and (2) geographical distribution of particulates should show a marked decrease with distance from the major source, over and above the decrease caused by dispersion (see later this section).

Figure C3 shows daily average soiling

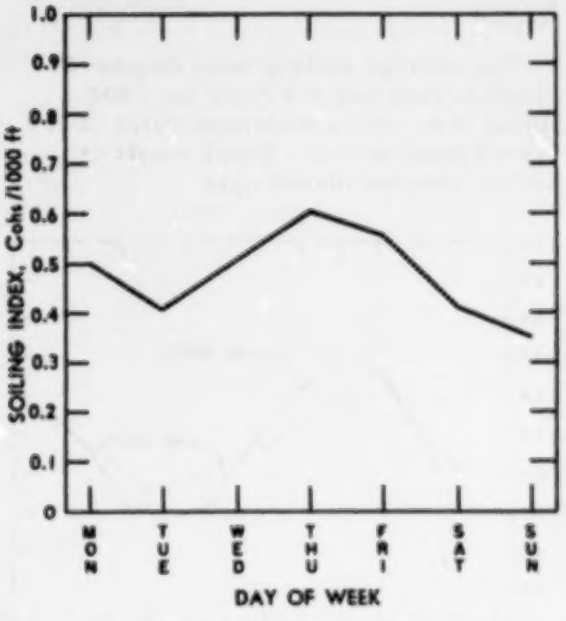


Figure 13. Soiling index vs. day of week.

indexes for the study. Analysis of data by time of day (Figure 12) shows a maximum soiling index during the period 6 to 8 am, a minimum during the period 2 to 8 pm, and a second maximum during the period 10 pm to midnight. This variation probably reflects changes in meteorological conditions. Analysis of data by day of week (Figure 13) shows a maximum on Thursday. Statistical analysis of these data indicates no significant day-of-week variation. This may be because the number of samples for the highly variable A.I.S.I. sampling was insufficient or because the conditions mentioned under "Particulate Levels" existed.

Sulfur Dioxide

The average 24-hour sulfur dioxide level during the period August 15 to September 20 was 16 parts per billion (ppb), with a maximum of 33 ppb. This is not excessive, as judged by comparison with urban areas in the United States, but is a relatively high level for this season in the area where the samples were located. It was obvious during the study (see later sections on geographical distribution and effects) that the Community Field station was not in the area of highest sulfur dioxide pollution.

The average sulfur dioxide level with the paper mill operating was 16.6 ppb; the average with the mill not operating was 3.0 ppb. Comparison of these two means leads to the conclusion that this difference is significant (t=4.3 for 31 degrees of freedom). Further analysis of sulfur dioxide levels indicates a positive correlation with percent of time the wind blows from the mill. The relationship may be simply expressed as SO_2 (in ppb) = 5.5 + 1.07 x percent wind from mill. For this location the wind from mill was taken as the 90-degree sector from NNE to ENE. Over the wind frequencies encountered (3-25 %) the correlation coefficient is 0.65, which is good for this type of analysis and the number of values (18) considered. A similar correlation is obtained if wind speed is also considered.

A good degree of correlation (r = 0.73 for 22 values) exists between suspended particulate level and sulfur dioxide. This relation is of the form: particulate ($\mu g/m^3$) = 123 + 4.2 x sulfur dioxide (ppb). This is in keeping with the hypothesis of a common source for these two pollutants.

Hydrogen Sulfide

Levels of hydrogen sulfide measured were low, reaching a maximum of 23 ppb for a 2-hour period. Frequency distribution of hydrogen sulfide levels is given in Table 31. It was possible on occasion to identify hydrogen sulfide by its odor.

Table 31. FREQUENCY DISTRIBUTION FOR HYDROGEN SULFIDE, COMMUNITY FIELD

Dates	Sample period duration, hr	Concentration of H_2S, ppb					
		0	1 - 5	6 - 10	11 - 20	21 - 30	Max.
Aug 3 to 17	2	123	32	5	1	1	23
Aug 18 to Sept 14	4	72	8	1	0	0	6
		Percent of samples in range					
Aug 3 to 17	2	76.0	19.7	3.1	0.6	0.6	
Aug 18 to Sept 14	4	89.0	9.9	1.2	0.0	0.0	

as distinct from the typical kraft mill odor. The odor threshold of this gas is reported in the literature as being from 25 to 1000 ppb (a 40-fold variation); a value of 800 ppb appears to be a reasonable value. That the level of hydrogen sulfide exceeded the odor threshold is not inconsistent with the low levels measured, considering the source of the gas, the method of measurement, and meterological influences.

ST. LOUIS HOSPITAL

At this station, sampling was conducted for particulates, hydrogen sulfide, and soiling for the period September 9 to 28. The average particulate level was 120 micrograms per cubic meter, with a range of 50 to 172. This lower value (cf 183 for Community Field) may be largely due to the much higher elevation of the sampler on the roof of the hospital. Analysis of particulate level with percent of time wind comes from mill shows a positive relation (r = 0.71). This equation is approximately: particulate ($\mu g/m^3$) = 54 + 14.8 x percent wind direction from ENE to S direction.

Hydrogen sulfide levels were essentially the same as those measured at Community Field (Table 32). Soiling levels recorded at the Hospital were low and erratic, and covered such a short period that no analysis of the data was made.

Table 32. FREQUENCY DISTRIBUTION OF HYDROGEN SULFIDE AT HOSPITAL

Concentration, ppb	Frequency		
	At Hospital		At Community Field
	Number	%	%
0	62	73.9	76.0
1 - 5	19	22.6	19.7
6 - 10	1	1.2	3.1
11 - 20	1	1.2	0.6
> 20	1	1.2	0.6
Maximum	a		a

[a]Maximum at both locations 23 ppb.

ODORS

The emission of malodors is a major aspect of the air pollution problem concerning kraft mills. The threshold odor levels for three of the major gaseous emissions from a kraft mill has been reported as 0.0011 milligrams per liter for hydrogen sulfide, methyl mercaptan, and dimethyl sulfide.[14] In parts per million by volume these levels would be 0.8 for hydrogen sulfide, 0.6 for methyl mercaptan, and 0.4 for dimethyl sulfide. Residents of Berlin reported that odor levels during the study were not as high as normal. Still, the presence of odors in the community was frequent. Insufficient data were taken to evaluate odor levels, but for a typical day during the study, when odors were present but not strong, it was noted that a dilution of 8 to 32 (8-32:1) would be necessary to reduce the odor level below threshold value. Odors also were emanating from the Androscoggin River as far downstream as Gorham. These odors probably resulted from wastes discharged into the river at Berlin.

GEOGRAPHICAL DISTRIBUTION

Sulfur Dioxide

Areal distribution of sulfur dioxide was measured on a monthly basis with lead peroxide candles. Several investigators have reported a correlation between average sulfur dioxide level and sulfation rate of lead peroxide cylinders.[35, 16, 41] Average sulfur dioxide equivalents of sulfation measured at Community Field agree with the values reported by Foran,[16] and these values are used in this section in reporting sulfur dioxide levels (Figure C4).

Sulfation rates for the nine-station network are given in Table 33. Sulfation rates for the 2-month period show a 5.5-fold increase from lowest to highest values. The four stations with sulfation rates greater than the average (426 μg SO_3 per 100 cm^2 per day) are Angel Guardian (792), Notre Dame (708), Community Field (496), and Derrah Street (443). These are the stations closest to the paper mill. These values and analysis

Table 33. AREAL DISTRIBUTION OF SULFATION RATES - NINE-STATION NETWORK

Station Name	Station Number [a]	Sulfation, $\mu g/100\ cm^2$ per day			Equivalent SO_2, ppb (1-mo avg)
		August	September	Average	
Airport Road	13	91	193	142	6
Community Field	5	616	977	496	14
Penstock	4	286	376	291	8
Powerhouse	1	512	466	389	11
Angel Guardian	8	600	983	792	22
Darrah Street	9	275	611	443	12
Notre Dame	12	348	1049	700	20
Berlin Jr. H. S.	10	188	517	352	10
St. Joseph	2	127	316	220	6
Average	-	285	569	426	12

[a]See Figure 1 for station locations.

of wind data support the contention that the main transport of pollution is along the valley and toward the east side. The relatively high values reported at stations 10 and 12 may be attributed largely to the "fumigation effect" of the morning break-up of the nighttime inversion (cf. sections on dispersion and effects).

If the city is arbitrarily divided into areas determined by topography as follows: a main valley (elevations less than 1100 feet), east side, southwest, and northwest, then the average sulfur dioxide levels shown in Table 34 indicate that the east side has the highest level of pollution, followed by northwest, valley, and southwest.

Table 34. AVERAGE GEOGRAPHIC DISTRIBUTION OF VARIOUS POLLUTANTS FOR AUGUST AND SEPTEMBER -- NINE-STATION NETWORK

Area	Station Number [a]	Sulfur Dioxide, ppb	Tons/mi^2 per 30 days			
			Total Dustfall	Insoluble Dustfall	Soluble Dustfall	Sulfate Dustfall
Valley	1, 2, 3	11	46	30	14	7
North (remote)	13	6	22	16	10	4
East Side	5, 9	17	37	22	15	6
Southwest Side	4	6	16	9	7	4
Northwest Side	10, 12	15	36	16	23	11

[a]See Figure 1 for station locations.

Total Dustfall

Total dustfall for the nine-station network is given in Table 35. A four-fold range of average values exists. The four stations with dustfall rates greater than the average (35 tons/mi^2 per 30 days) are Community Field (66), Angel Guardian (48), Notre Dame (47), and the Powerhouse (41). The geographic distribution of dustfall shows that the areas of highest pollution are near the paper mill and down the valley. Results by generalized areas are indicated in Table 34. The level of dustfall throughout the community is comparable to that in large urban areas and is indicative of a need for reduction.

Table 35. AREAL DISTRIBUTION OF TOTAL DUSTFALL -- NINE-STATION NETWORK

Station	Station Number [a]	Total Dustfall per 30 days, tons/mi^2		
		August	September	Average
Powerhouse	1	27.92	53.55	40.74
St. Joseph	2	12.42	19.05	15.74
Penstock	4	-	25.22	25.22
Community Field	5	63.81	68.29	66.05
Angel Guardian	8	43.83	52.26	48.04
Darrah Street	9	21.23	29.77	25.50
Berlin Jr. H. S.	10	24.71	27.12	25.92
Notre Dame	12	36.96	59.04	47.00
Airport Road	13	25.44	13.90	19.67
Average	-	31.79	38.69	34.88

[a]See Figure 1 for station location.

Components of Dustfall

The total dustfall was further analyzed for insoluble fraction, soluble fraction, and sulfate fraction. Results of these analyses are shown in Tables 36, 37, and 38. Insoluble dustfall was higher than the average (21 tons/mi^2 per 30 days) at Community Field, Angel Guardian, and Powerhouse; soluble dustfall was higher than average (14 tons/mi^2 per month) at Notre Dame, Community Field, and Angel Guardian. Sulfate dustfall was higher than average (6 tons/mi^2 per month) at the same three stations. Geographical distribution by area is shown in Table 34.

Table 36. AREAL DISTRIBUTION OF INSOLUBLE DUSTFALL -- NINE-STATION NETWORK

Station	Station Number[a]	Dustfall per 30 days, tons/mi^2		
		August	September	Average
Powerhouse	1	19.07	66.72	31.60
St. Joseph	2	9.95	12.80	9.38
Penstock	4	--	20.37	20.37
Community Field	5	35.56	61.20	36.38
Angel Guardian	8	22.84	33.18	23.01
Derrah Street	9		20.86	15.68
Berlin Jr. H. S.	10	10.98	16.00	13.49
Notre Dame	12	17.05	20.74	19.30
Airport Road	13	11.23	9.23	10.23
Average	-	16.67	26.36	20.72

[a]See Figure 1 for station location.

Table 37. AREAL DISTRIBUTION OF SOLUBLE DUSTFALL -- NINE-STATION NETWORK

Station	Station Number[a]	Soluble Dustfall per 30 days, tons/mi^2		
		August	September	Average
Powerhouse	1	9.88	8.83	9.36
St. Joseph	2	6.47	6.25	6.36
Penstock	4	-	6.85	6.85
Community Field	5	28.25	27.09	27.67
Angel Guardian	8	20.99	19.08	20.04
Derrah Street	9	10.36	8.91	9.63
Berlin Jr. H. S.	10	13.73	11.12	12.42
Notre Dame	12	17.11	38.30	27.70
Airport Road	13	10.21	6.67	8.44
Average	-	15.12	14.34	14.16

[a]See Figure 1 for station location.

Generalization

The general nature of its air pollution (cf. general sources) and its specific industrial emissions (cf. source study) leads to the following generalizations about the geographic distribution of air pollution in Berlin. Process emissions primarily affect stations 5, 8, and 12 and carry to a lesser degree to stations 10, 9, and 1. Thus the general areas affected are the northwest, east side, and valley. Non-process emissions primarily affect stations 1, 5, and 8 and to a lesser extent stations 4, 12, and 9. Hence, the general areas affected are the valley and east side.

The stations with generally higher pollution levels are 5, 8, and 12 and to a lesser extent number 1. Hence it is concluded that pollution is heaviest in areas near the paper mill and that this pollution tends to carry down the valley to some extent. A contributing factor to the pollution measured at station 1 may be the stack of the power plant at the Cascade mill. Areas considerably north of the paper mill, in the southwest section of the city, and out Route 110 have lower pollution levels than those cited above.

Table 38. AREAL DISTRIBUTION OF SULFATE DUSTFALL -- NINE-STATION NETWORK

Station	Station Number[a]	Sulfate Dustfall (SO_3) per 30 days, tons/mi^2		
		August	September	Average
Powerhouse	1	5.69	6.49	5.59
St. Joseph	2	1.32	3.07	2.20
Penstock	4	-	2.65	2.65
Community Field	5	13.33	15.43	14.38
Angel Guardian	8	7.07	11.57	9.32
Derrah Street	9	2.01	1.84	1.92
Berlin Jr. H. S.	10	5.24	6.43	5.84
Notre Dame	12	9.98	23.16	16.26
Airport Road	13	1.11	1.97	1.54
Average	-	5.66	7.82	6.66

[a]See Figure 1 for station location.

TEMPORAL VARIATION

Three stations, Angel Guardian, Community Field, and Berlin Junior High School, were operated from August 1960 through May 1961. Analyses were made for sulfur dioxide (by lead peroxide candles) and dustfall (total, insoluble, soluble, and sulfate) at these sites. Temporal variation of pollution, as indicated by the three-station network, is shown in Figure 14. Generally, sulfate dustfall and soluble dustfall decrease from August until they reach a minimum in December, and then gradually increase through April. Insoluble dustfall gradually increases from August, to a maximum in February, and then decreases sharply. Sulfur dioxide shows a more erratic pattern, increasing sharply from August to a maximum in October, decreasing sharply through December, and then increasing more gradually through April.

It is normally expected that the influx of cold weather, with its attendent increase in heating needs, results in greater pollution loads. Heating degree-days were used, as a measure of this

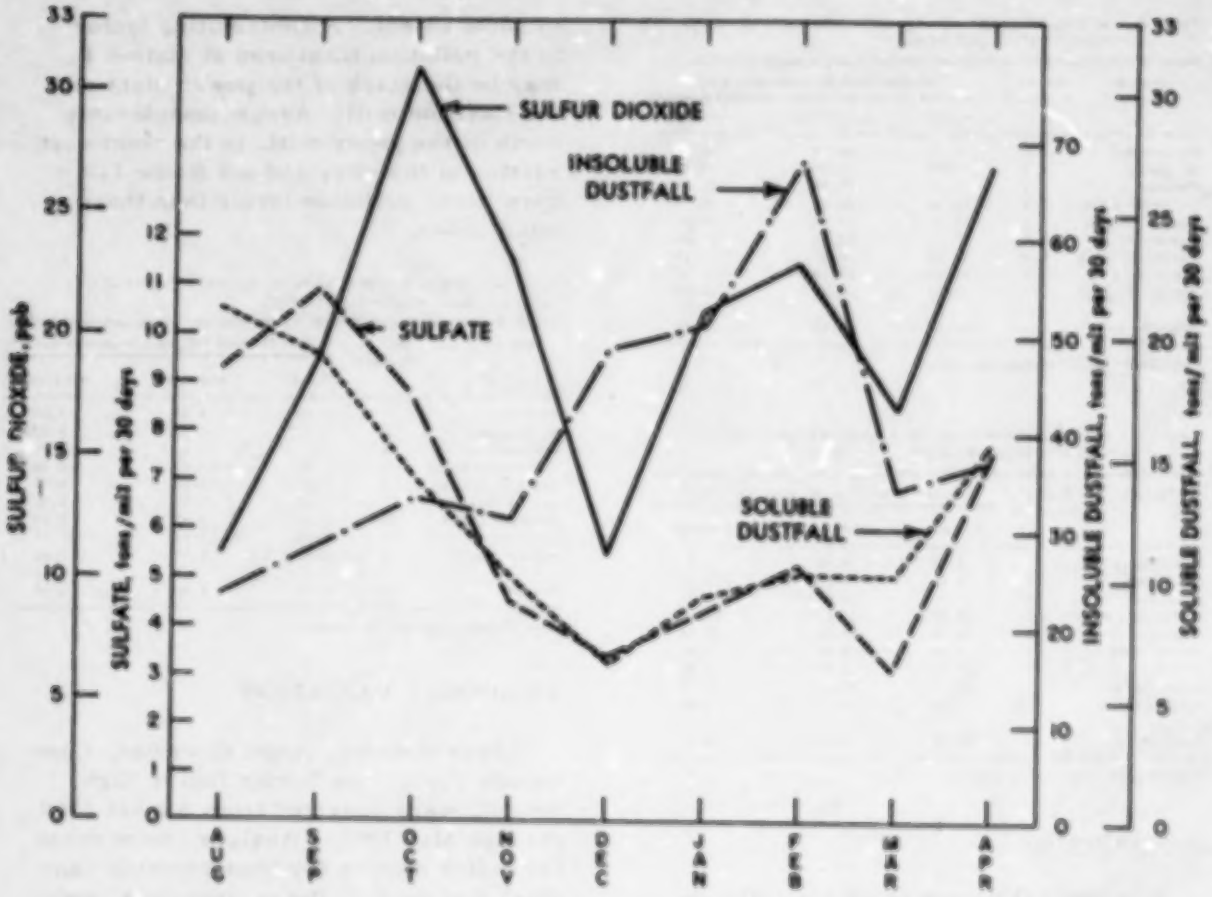


Figure 14. Temporal variation of pollution - three-station network.

increased need for heating, to determine for nine monthly values: insoluble dustfall has a correlation coefficient of +0.78; sulfate and soluble dustfall, -0.94; and and sulfur dioxide, +0.06. Hence, with the possible exception of insoluble dustfall, advent of the heating season does not bring about a corresponding increase in pollution. This is indicative that pollution from heating requirements is not significant compared to industrial process emissions.

For the 9-month period, the three-station network indicated the following average levels of pollutants: sulfur dioxide, 731 micrograms SO_3 per 100 square centimeters per day (21 ppb); sulfate dustfall, 8.16 tons/mi^2 per 30 days; and total dustfall, 60.58 tons/mi^2 per 30 days (44.86 insoluble and 15.72 soluble).

EFFECTS OF POLLUTION

Possible effects of air-borne emissions from sulfate pulping are numerous. They include health impairment, damage to property, damage to vegetation, visibility interference, and nuisances.

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HEALTH EFFECTS

No health survey was undertaken as a part of this study, and it is not the intent of this study to inquire into the impact of pollution on the health of Berlin residents; however, conditions deemed to be unsatisfactory should be pointed out. Health hazards from air pollution are generally thought of in two classes, episodic (as the Donora incident) and chronic, long-term effects. Although a growing body of circumstantial evidence links air pollution and chronic health impairment, at this stage in the understanding of air pollution's role in chronic health impairment nothing is known concerning the specific materials emitted from sulfate pulping operations. Acute health hazards from concentrations of gases found in the area around such operations are generally not regarded as serious. The acute toxicity of the compounds that might be involved, sulfur dioxide and hydrogen sulfide, is well known. Little is known about the toxicity of the true air pollution signatures of sulfate pulping: mercaptans, dimethyl sulfide, and dimethyl disulfide. Very limited data indicate that hydrogen sulfide is about 10 times more toxic to rats than disulfide and mercaptan. Thus from observations on the concentration of hydrogen sulfide in the vicinity of sulfate pulping mills, it has tentatively been concluded that toxic gases are not at sufficient concentration to justify serious concern regarding acute health effects. The possibility of long-term health impairment (chronic health effects) due to air pollution is of concern to medical researchers. The independent work done by Dr. Ferris of the Harvard School of Public Health, on the health of Berlin residents, is of great interest in this field of inquiry.

The development of standards for ambient air quality, similar to such standards in the fields of water sanitation, radiation, and industrial hygiene, is a pressing need in air sanitation. Two governmental bodies have proposed such standards, California[34] and Russia.[27] Available standards that apply to pollutants measured in Berlin are given in Table 39. The standards set by the U. S. S. R. are generally considered low, and the body of experimental work supporting these standards needs and deserves careful study and evaluation. In a comparison of pollutants measured at Community Field with the Russian standards: hydrogen sulfide exceeded the standard in 3 percent of samples (8 of 253), sulfur dioxide in 0 percent, particulate levels in 72 percent. Odors in themselves are not generally considered a health hazard, but they may constitute a nuisance.

Table 39. STANDARDS FOR AMBIENT AIR QUALITY

Pollutants	California[a]	U.S.S.R.[b]	
		Single sample	Daily average
Sulfur dioxide, ppb	500[c]	190	57
Hydrogen sulfide, ppb	-	21	7
Particulate, $\mu g/m^3$	-	500	150

[a]Reference 34.
[b]Reference 27.
[c]Adverse level pertaining only to reducing-type pollution during periods of inversion.

PROPERTY DAMAGE

Damage to structural materials and painted surfaces has been reported in other areas from particulate matter and sulfur-containing gases emitted from sulfate mills. Particulate fallout damages materials and painted surfaces and contributes to the general dirtiness of the surrounding area. Discoloration of lead-base paint by hydrogen sulfide is common around sources of this gas. A recent study by the paint industry[44] indicates that any concentration of hydrogen sulfide present in the atmosphere will in time produce darkening of paint containing lead pigments if the paint surface is wet with water; this darkening is delayed if the lead content of the paint is low.

One incidence of paint blackening occurred during the study, on September 22. The paint on several houses in the northwest section of the city turned black overnight. Paint samples taken from one of the affected houses were found positive for sulfide damage. On September 1 lead acetate tiles prepared in the manner described by Chanin[8] were placed at 10 sampling stations. The next day tiles placed on the east side of the city were found blackened. Those found darkened, listed in order of decreasing blackness, were at the following stations: Derrah Street, Angel Guardian, Community Field, King School, the Powerhouse, and Berlin Foundry. Those stations showing no change were: Penstock, Route 16-A, Notre Dame, and Berlin Junior High School. The stations affected cover a large geographical area. These two studies show that the level of hydrogen sulfide and other necessary conditions are sufficient to damage paint in Berlin.

At six stations (the Armory, Berlin Foundry, King School, Angel Guardian, Berlin Junior High School, and Notre Dame) various fabrics (wool, cotton, rayon, and nylon) were exposed. Although the fabrics were extremely soiled, only the rayon and nylon fabrics from Berlin Junior High School showed any other damage that might be attributed to air pollution. Microscopic examination of the damage was inconclusive.

Other property damage includes increased corrosion of metals, damage to building materials, increased soiling of laundry, home furnishings, and display merchandise, and similar effects.

DAMAGE TO VEGETATION

Air pollution can cause injury to plant life. Commercial agricultural crops, forests, parks, and ornamental plantings have all been injured. Different species and varieties of plants vary greatly in their response to air pollution. Some plants are often the most sensitive indicators of contaminants in the atmosphere; damage to vegetation is often used to indicate presence of various pollutants and the possible concentrations of these pollutants. As part of this study, a representative of the Department of Agriculture visited Berlin on October 22 and 23 to examine for possible air pollution effects on vegetation.

One area of serious SO_2 injury was found in a rougly elliptical pattern north of the paper mill, with the principle axis near Prospect Street. The region along the river (Main Street), from about the courthouse northeast to the fire station at 7th, showed variable evidence of periodic SO_2 fumigations of the species along this route a few would be considered sensitive to SO_2. It is perhaps significant that a "wild" vetch, which was common to vacant property and roadsides elsewhere in the valley, was less common along this route. Where this vetch was found, it generally showed necrotic edges and intercostal areas on the upper leaves. Along Main Street, from about Church Street to possibly 100 yards east of Success Street, injury was very severe. Leaves on plantings in front of the hospital were practically all dead. This pattern of heavy damage extended north along Prospect Street, widening up the hill away from the river. In the vicinity of Prospect Street and Hillside Avenue the injury was particularly severe. Some barberry showed 100 percent leaf injury. Apple, ash, lilac, and some other trees showed up to 75 percent leaf destruction. The injury decreased further north on Prospect; however, markings in trees, particularly poplar, were clearly seen well beyond Portland Avenue and Prospect. East of Prospect the easily recognizable injury extended to the Highland Park Development Area. The western edge of the area was about High Street and Hillside Avenue. Occasional severe markings were found along both sides of High Street as far north as Portland. South of Hillside along High Street very little injury occurred.

It was difficult to determine whether this severely damaged area had been periodically fumigated; however, at least one very severe fumigation had affected this limited area probably 3 to 4 weeks prior to the visit.

Occasional markings typical of SO_2 damage were found elsewhere in the city, particularly on the vetch, some grasses, apple, spirea, poplar, the occasional pine, and lilac. The region of Angel Guardian School showed very slight markings of probably two different fumigations. Occasional markings were found along Green Street as far northwest as 4th Avenue. It was impossible to tell how many different fumigations had occurred or at what times.

Sulfur dioxide injury is sufficiently typical to leave little question of the causative agent. The severity of the injury would indicate fumigations of several parts per million. The general dirtiness of the vegetation throughout the urban area indicates a rather high particulate loading of the atmosphere. We do not know if this has a serious effect on vegetation or not. In general, the vegetation of the area was in poor condition.

The areas of severe vegetation damage are shown in Figure 15. It is of interest to note that the large elliptical area generally corresponds to the area that could receive the morning fumigation effect of the MGO stack, a major source of sulfur dioxide (cf. section on dispersion).

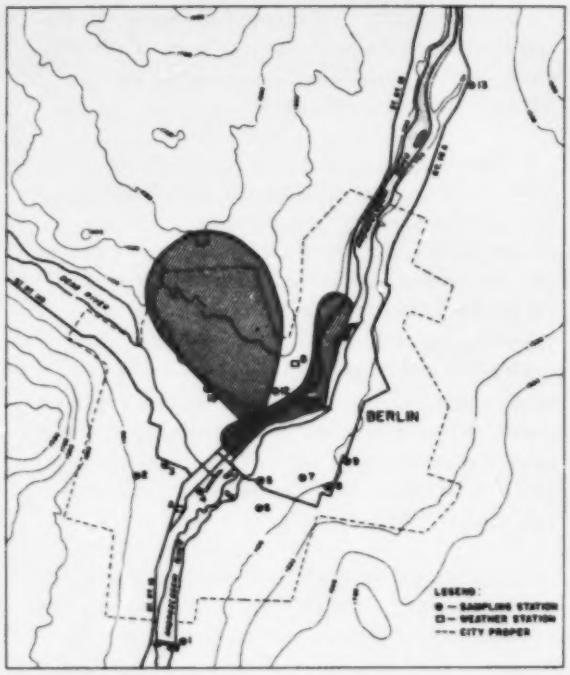

Figure 15. Areas of severe air pollution damage to vegetation.

NUISANCE EFFECTS

Among the major nuisances resulting from air pollution in Berlin are foul odors, heavy dustfall, lowered visibility, and soiling. Malodors from the kraft pulping operations are generally considered to be obnoxious, have an adverse psychological effect on the population, and detract from the possible development of tourism. Heavy dustfall in areas near the mill and generally throughout the city leaves deposits on cars, porches, laundry, sills, etc., imparting a dingy appearance to the area.

SYNOPSIS

A cooperative survey to evaluate the air pollution situation in Berlin, New Hampshire, was undertaken by the Public Health Service, New Hampshire State Department of Health, and City of Berlin Health Department. The survey was to appraise the nature, sources, extent, and effects of air pollution in Berlin. Air pollution is the presence in the ambient atmosphere of substances, put there by the activities of man, in concentrations sufficient to interfere directly or indirectly with his comfort, safety, or health, or with the full use and enjoyment

of his property. Air pollution problems exist in Berlin and have reached levels that justify constructive efforts to ameliorate the situation.

The major source of air pollution in Berlin is industry, specifically the pulping and auxiliary operations. Other sources do not play an important role in the over-all situation. Pollutants of concern include particulates, sulfur oxides, hydrogen sulfide, and malodorous reduced-sulfur gases. The major sources of these pollutants are the recovery furnace, blow system, lime kiln, and chemical recovery system of the kraft mill, the MGO stack of the sulfite mill, and the Heine boiler plant.

Levels of suspended particulate matter, dustfall, and sulfur oxides are high compared to those measured in other areas. The levels of hydrogen sulfide and malodors although not generally or consistently high do reach levels at which undesirable effects are pronounced.

The valley topography greatly influences the meteorological regime and handicaps the ability of the atmosphere to disperse pollutants adequately. Inversions are frequent, and visual manifestation of the inversion and its morning break-up are readily apparent.

Undesirable effects of pollution include soiling, excessive dustfall, paint damage, vegetation damage, and unpleasant odors. The need for alleviating these conditions is apparent.

Complete control of pollutant emissions probably cannot be obtained. Although solutions to some of the pollution problems are very difficult and may be economically unwarranted, certain measures can be undertaken that may result in a considerable improvement in pollution emissions; certain measures and evaluations to this effect are presented.

SOLVING THE PROBLEM

Emissions from other than industrial processes are not of sufficient magnitude to warrant consideration of control measures for these sources. Improvement in air quality can result from solving the problem of industrial emissions. Of immediate concern and obvious notice are emissions of particulates, sulfur dioxide, hydrogen sulfide and organic sulfur gases, and odors. Principal sources are sulfate pulping operations, MGO recovery and sulfite operations, and steam-raising operations.

SULFATE PULPING OPERATIONS

Solutions to some of the air pollution problems facing the industry do not come easily. "Is it possible to build and operate a completely odorless kraft mill?"[49] The answer to this question is only partly a technical one. "Technically the answer is that a completely odorless mill is possible if management is prepared to pay the price. A preliminary consideration of the technical problems suggests that the direct costs of a complete odor control system would not be excessive nor would they all be pure outgo."[49]

Particulate Emission

Particulate emissions originate largely from the recovery furnace, smelt tank, and lime kiln.

The dust content of the furnace gas is fairly great, in the order of 100 pounds per ton of pulp produced; it is normally made up of minute particles less than 1 micron in diameter. The installation of an electrostatic precipitator, which is an economic necessity to the operation of a

kraft pulp mill, removes about 85 to 95 percent of this material. The balance of the dust escapes to the atmosphere. During its passage through the precipitator, the dust is largely flocculated so that this material that escapes consists largely of fluffy aggregates up to 1 millimeter in diameter and of fine particles comparable to ordinary industrial smoke. It is mainly the large aggregates that settle out within a mile or two of the stack, and there, contribute to the overall dustfall and damage paint and vegetation. To improve recovery of saltcake from this source (and reduce atmospheric emissions), secondary scrubbers, following the precipitator, have been installed in some instances. An added dividend is obtained since these scrubbers also collect some gaseous material. Venturi scrubbers and spray-type washers are popular secondary scrubbers, and weak black liquor or water is used as the scrubbing medium. Some effective demister is required after the scrubber; this may take the form of a tall stack. Secondary scrubbers installed in mills reportedly perform satisfactorily.[19] Present particulate emissions from recovery furnaces in Berlin amount to over a ton per day; use of a secondary scrubber should easily reduce this and also recover perhaps 0.5 ton of saltcake per day.

The smelt dissolving tank stack is equipped with a water spray; emissions from this source amount to 65 pounds per hour at a loading of 0.4 grain per cubic foot. Most of this is undoubtedly mist carryover. Mesh demisters may be effective in reducing this emission. At one installation[6] it was reported that 99 percent of all droplets over 5 microns were recovered.

Emissions to the atmosphere from the lime kiln amount to 100 pounds per hour at a loading of 0.6 grain per cubic foot. This is about par for the source as compared to values reported in the literature. The lime kiln stack in Berlin is equipped with water sprays of unknown operating conditions and efficiencies. The dust from lime kilns has been a major nuisance of sulfate mills, and it is remarkable that the problem of collection of these relatively large particles has not been thoroughly investigated. Collins[11] reports that efficiencies of approximately 99 percent removal of lime dust are achieved at relatively low pressure drops with a modification of a venturi scrubber. Vigilance in maintenance and operation of the present sprays may lead to decreased emissions. It is suggested that the efficiency of the water sprays be checked by sampling upstream and downstream from the washer; efficiencies should run 80 to 85 percent, and if less than this, some maintenance or alteration is called for.

Odor Emission

As has been stated, major sources of odor are digester gases, evaporator gases, and furnace gases. In addition a number of sources of lesser magnitude exist.

Elimination of odors from digester gases can be accomplished by collection and oxidation of blow gases and relief gases. The most satisfactory means of collection apparently is removal of the condensable fractions followed by storage of the noncondensables in a floating cover or diaphram gas holder. Oxidation of the collected gases is accomplished by burning in the lime kiln or in special furnaces, or by mixing the gases with effluent from the bleach plant.[9, 12]

Oxidation of black liquor before evaporating and burning prevents the formation of many of the odorous compounds otherwise released. Sulfur losses from the evaporators are reduced by more than 90 percent,[10] and odors are very greatly curtailed.[49] Odors from the recovery furnace also are reduced. Better liquor burning in the furnace may also be achieved.[19]

In most sulfate mills improved design and improved operation of the recovery furnace can pay big dividends. Adequate secondary air and sufficiently high temperatures can result in greater heat recovery, reduction in odor emission, and reduction in sulfur losses. Improved operation of the furnace also reduces the emission of hydrogen sulfide.

MGO RECOVERY

Emission of sulfur dioxide from the MGO stack, as evidenced by measurement, observation, and vegetation damage, is of sufficient magnitude to require investigation into control measures. The flue gas from the boiler contains 0.8 percent sulfur; it is essential to the economic operation of the system that this sulfur be recovered. The present recovery system should be adequate for recovering the sulfur dioxide from the flue gas. Excessive emissions of the gas may be due to improper operation or gross systems failure. Additional control equipment should disclose the reason for the emission, and corrective action should be taken.

BOILER PLANT

Particulates

The boiler plant constitutes the major source of particulate emissions. Control of this source would materially reduce dustfall in Berlin. The control of emissions from power plants is technically feasible. The cost of control equipment is substantial, and generally no economic return is realized. Electrostatic precipitators are the choice of control equipment. At 98 percent efficiency, the cost of equipment and installation runs approximately one dollar per minute per cubic foot of gas handled (in the 100,000 to 400,000 cfm range); this cost is competitive with that of other equipment capable of yielding comparable efficiency. Above 98 percent efficiency the cost figure climbs rapidly. Legislation currently being considered by the Congress of the United States may ease the economic burden by allowing accelerated amortization of air pollution control equipment for tax purposes. New Hampshire law provides for limited tax exemption for equipment to control a source of air pollution.

Sulfur Oxides

Control of sulfur oxides from power plants is generally not technically feasible at this time. With the low sulfur content of coal burned in the Heine plant, emission of sulfur oxides is not of immediate concern.

INITIAL STEPS

What steps then should be taken to reduce emission of pollutants to the atmosphere of Berlin? The following initial steps are warranted:

1. Evaluate the sulfur dioxide emission of the MGO stack over a period of at least a month, covering all operating conditions. Samples should be taken directly from the stack through the existing sample tap (the aspirator line now being used is not adequate).

2. Inspect the venturi-separator packed-tower system of the MGO plant for condition of equipment; investigate the operation of this system for adequacy.

3. Evaluate the efficiency of the lime kiln spray washer by sampling for particulate up- and down-stream. If this efficiency is less than 85 percent, modification of the spray washer or of its operation is warranted.

4. Evaluate the use of secondary scrubbers on the recovery furnace stack. A cost efficiency study may disclose that all or a substantial portion of the cost of such equipment may be offset by recovered saltcake and sulfur compounds.

5. Install a mesh demister on the smelt (dissolving) tank stack.

6. Consider the possibility of black liquor oxidation. This is partly an economic consideration but more a process consideration, since it decidedly alters the process of pulp production.

7. Evaluate the cost of installing equipment for collecting and destroying blow and relief gases from the kraft digesters and for collecting particulates from the Heine boilers. The cost of such equipment, which does not result in any economic advantage of recovered product, must be balanced against anticipated emission reduction with resulting community good will and better public relations.

8. Above all, proper operation of the recovery furnace and Heine boilers must be insured. This consideration should materially help reduce the magnitude of emissions. Proper maintenance and operation of existing control equipment (MGO venturi scrubbers, lime kiln spray, smelt tank spray) must be maintained.

9. Production capacity should not be greatly exceeded; overloading the equipment greatly increases pollutant emission.

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APPENDIX A. METHODOLOGY

The methods used for the determination of atmospheric pollutants are listed here. For brevity the methodology is not detailed; interested parties may find the complete methods in the references cited.

1. Dustfall. Monthly samples of dustfall were collected in polyethylene containers measuring 7-3/4 inches in diameter at the top and 10-3/4 inches high. Water and an algicide were placed in each container. Analyses were run for total water-insoluble matter, water-soluble matter, and sulfate.[21]

2. Sulfur Dioxide. (a) Monthly values of sulfation rate were determined by the lead-peroxide candle method,[45, 26] as modified by the Tennessee Valley Authority.[35] Results may be used to obtain an estimate of mean sulfur dioxide levels.[13] (b) Daily values of sulfur dioxide levels were obtained by the volumetric method described by West and Gaeke,[47] modified.

3. Suspended Particulate Matter. High-volume samplers[32] were operated for 24-hour periods, flash-fired glass fiber filters were used.[7] Samplers were operated in vertical position, and the total weight of particulate matter collected was determined gravimetrically.

4. Soiling. Soiling power of suspended particulate matter was determined on a 2-hourly or 4-hourly basis. A. I. S. I. type strip filter paper samplers[24] with Whatman No. 4 filter paper were used. For soiling evaluations a manual spot evaluator was used to measure light transmission.

5. Hydrogen Sulfide. Hydrogen sulfide levels were measured by three methods. (a) Relative exposures of various areas of the city were measured by lead-acetate-impregnated ceramic tiles, as described by Chanin.[8] (b) Two-hourly and four-hourly levels of hydrogen sulfide were measured with lead-acetate-impregnated tape and a modified A. I. S. I. strip filter paper sampler.[31] A manual spot evaluator was used to evaluate samples. (c) Daily levels of H_2S were measured volumetrically; a methylene blue method[21] was used after a modification in which cadmium hydroxide scrubbing solution was replaced with zinc acetate.

6. Odor Levels. Odor levels were measured with the Scentometer developed by the City of Cincinnati, Bureau of Air Pollution Control and Heating Inspection,[20] under a PHS demonstration grant.

7. Fabric Deterioration. Four types of fabric were exposed for the study duration for evaluation of fabric deterioration caused by air pollutants. The fabrics used were rayon, nylon, cotton, and wool.

8. Meteorological Measurements. Continuous measurements were made of wind direction, wind speed, temperature, and relative humidity. Wind direction and speed were measured by Beckman-Whitley Wind Systems.[4] Temperature and relative humidity were measured with recording hygrothermographs.[17]

9. Stack Sampling. (a) Recovery furnace stack. Evaluation of emissions from this source was made with a sampler and method developed by Hendrickson at the University of Florida[25] and also a gas chromatographic technique developed by Adams at Washington State University.[1] (b) Smelt tank stack and blow system (accumulator and relief).

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Emissions from these sources were evaluated with the sampler developed by Hendrickson.[25] (c) MGO stack. Measurements were made of particulate[25] and sulfur dioxide[47] emissions. (d) Lime kiln. Measurements were made of particulate,[48] sulfur dioxide,[47] and hydrogen sulfide[25] emissions. (e) Power plant boiler. Measurements were made of particulate[48] and dense smoke[28] emissions. (f) Emission rates. General procedures followed in measuring stack gas velocities, humidities, etc. were taken from publications by Western Precipitation Corp.,[48] Badziock[3], Rossano,[29] and American Industrial Hygiene Association.[2]

APPENDIX B. EXAMPLE OF POLLUTION EMISSION RATES

The data presented in this appendix are of value only as general information on the composition and magnitude of pollution from several activities. They should not be applied to any specific situation without due consideration of the many factors that affect pollution emissions.

Table B 1. COAL[40, 30] -- Pounds of Pollutants Emitted per Ton Burned

Component	Industrial[a]	Domestic Commercial[a]
Sulfur dioxide (as SO_2)	3460 S	3600 S
Sulfur trioxide (as SO_3)	420 S	80 S
Hydrogen sulfide (as H_2S)	8 S	8 S
Nitrogen oxides (as NO_2)	20	0.4
Fluorides (as HF)	0.4	0.4
Organics (as CH_4)	-	30
Particulate	1500 A[b]	24[d]
	300 A[c]	12[e]

[a]S = lb of sulfur per lb fuel; A = lb of ash per lb fuel.
[b]Pulverized coal
[c]Under fired, traveling grate.
[d]Hand fired.
[e]Stoker fired.

Table B2. FUEL GAS AND OIL[33, 40] -- Pounds of Pollutants Emitted per 1000 Pounds Burned

Component	Gas[a]	Oil[b]
Sulfur oxides (as SO_2)	-	30.0
Nitrogen oxides (as NO_2)	6.9	13.5
Hydrocarbons (as CH_4)	1.5	5
Organic acids (Acetic)	1.2	15
Aldehydes (as CH_3CHO)	1.0	1.8
Particulates	-	0.25

[a]1000 pounds of gas is equivalent to approximately 21,785 cubic feet.
[b]1000 pounds of No. 2 fuel oil is equivalent to approximately 140 gallons.

Table B3. INTERNAL COMBUSTION ENGINES[8A] -- Pounds of Pollutants Emitted per 1000 Gallons Burned[a]

Component	Automobiles	Diesel
Hydrocarbons	332	180
Aldehydes	4	10
Other organics	5	-
Sulfur oxides	9	40
Nitrogen oxides	113	100
Particulate	11	110

[a]A wide range of emission values is reported in the literature; emissions are highly variable.

Table B4. WASTE INCINERATORS[33, 24] -- Pounds of Pollutants Emitted per 1000 Pounds of Material Burned

Component	Household	Municipal
Sulfur oxides (as SO_2)	4	1
Nitrogen oxides (as NO_2)	2	1
Aldehydes (as HCHO)	18	0.7
Organic acids (acetic)	4	0.3
Organics	818	0.6
Ammonia (as NH_3)	8	0.2
Particulate	13	12

Table B5. BURNING DUMPS[15] -- Pounds of Pollutants Emitted per Day per 100,000 Persons Using Dump

Principal Contaminants	
Sulfur oxides	180
Nitrogen oxides	90
Ammonia	345
Aldehydes	600
Organic acids	225
Organics	42,000
Particulate	7,000
Total	50,400

Table B6. WOOD WASTES[40] -- Pounds of Pollutants Emitted per 1000 Pounds Burned

Component	
Sulfur oxides (as SO_2)	0.08
Nitrogen oxides (as NO_2)	0.6
Hydrocarbons (as CH_4)	10
Organic acids (as acetic)	0.2
Aldehydes (as CH_3CHO)	0.9
Fluoride (as HF)	0.003
Particulate	1.3

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APPENDIX C. DETAILED RESULTS

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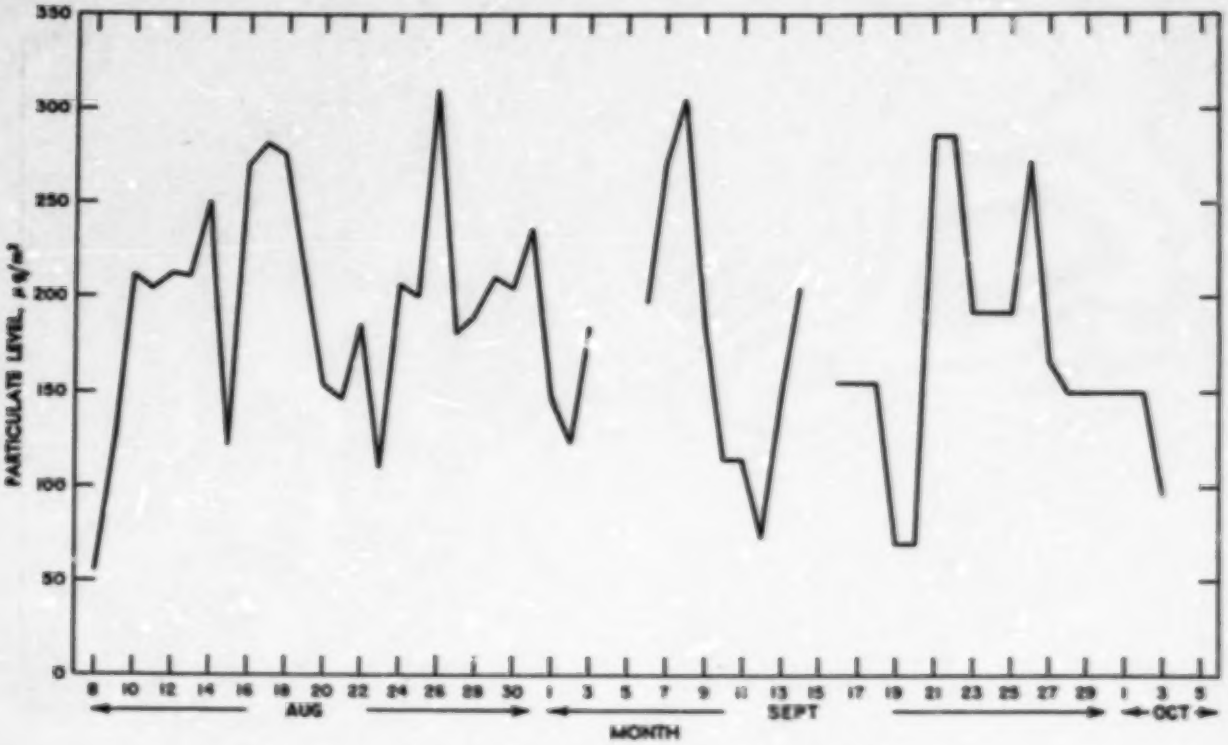

Figure C1. Particulate level vs. date Community Field.

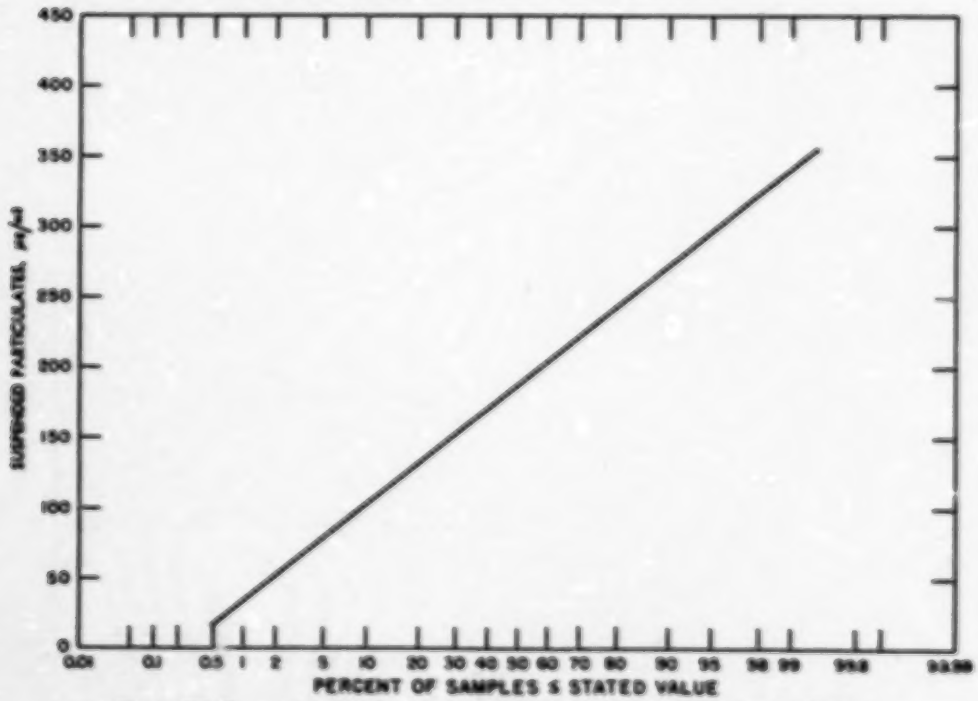

Figure C2. Frequency distribution of suspended particulate - Community Field.

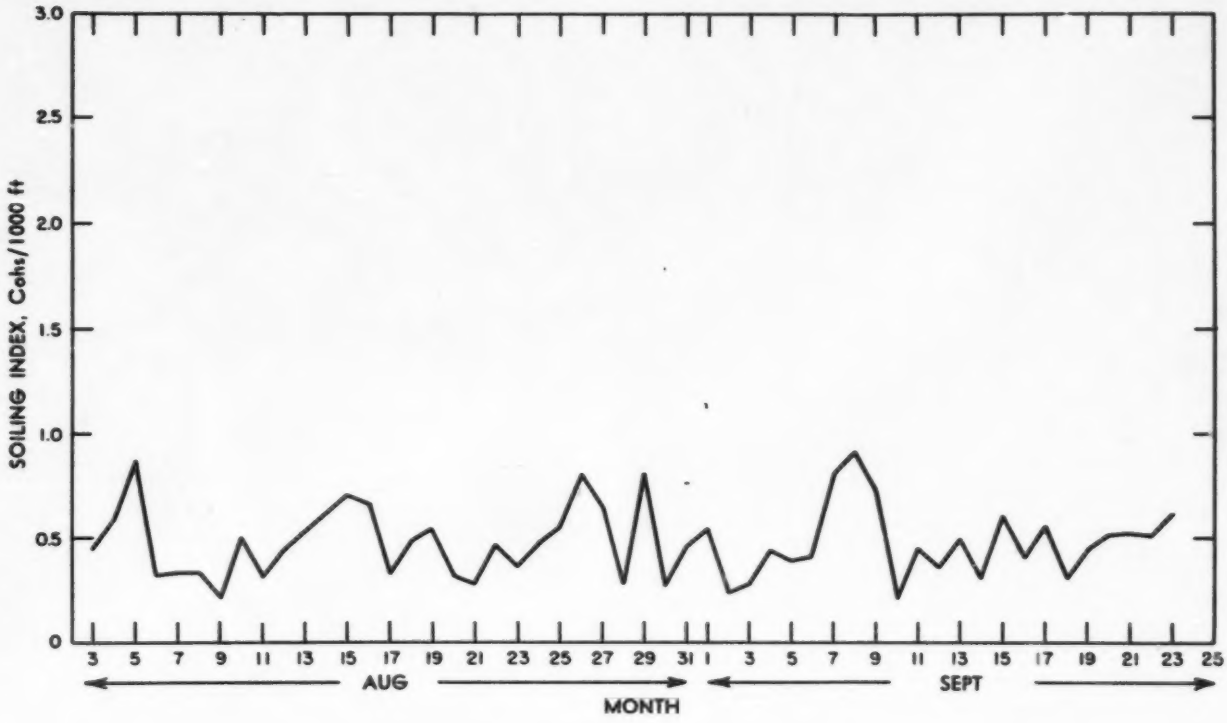

Figure C3. Soiling index vs. date - Community Field.

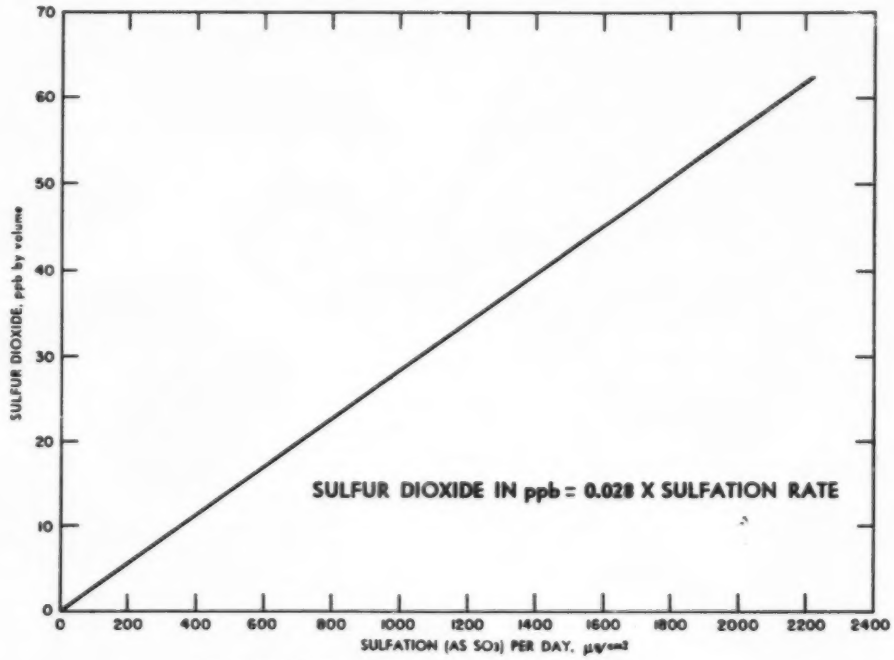

Figure C4. Sulfur dioxide equivalent of sulfation rate.